Title	Genetic and phenotypic aspects of performance in farmed red deer
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Qualification	PhD
Year	1991

Genetic and Phenotypic Aspects of Performance in Farmed Red Deer

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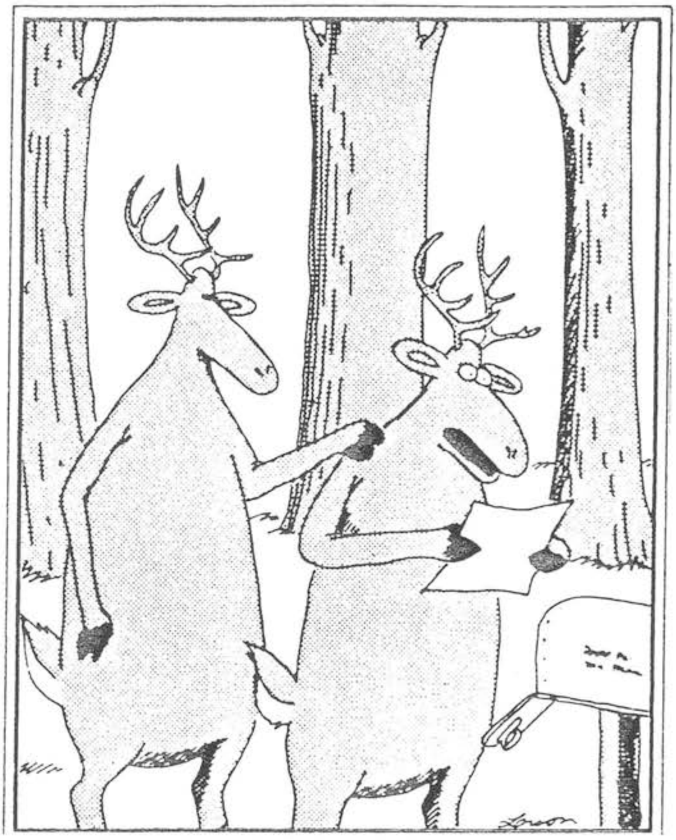
A thesis submitted for the degree of Doctor of Philosophy in the Faculty of Biological Sciences, University of Oxford, Trinity Term 1991



"Oh my God! It's from Connie! She's written me a 'John deer' letter!"

From The Far Side Gallery 3
by Gary Larson
1988 Futura Publications

DECLARATION

I declare that this thesis is my own composition and reports analysis of data done by me. The data for this study was collected by me unless mentioned in the text.

Connie McManus
August 1991

ABSTRACT

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D.Phil
Trinity Term 1991

Genetic and Phenotypic Aspects of the Performance of Farmed Red Deer

This thesis examined genetic and phenotypic aspects of production of farmed Red deer in the UK.

Heritabilities for weight traits tended to be moderate to high. Selection on weight at a given age will tend to lead to a correlated increase in weight and all ages and has implications for increased calving difficulty and higher maternal overheads. Animals of Wapiti and Eastern European parentage tended to have higher liveweights than those of British parentage pointing to their possible use as 'terminal' sires. Care is needed when selecting hinds to cross with these stags. Older dams were more likely to have a successful pregnancy and calve earlier. Calving traits tended to have low genetic variation.

A central performance test was set up to improve across herd linkages. It is concluded that in future the test should start earlier and a lower limit on the weight of animals going on test should be set.

The traits that were included in the economic breeding objective for Red deer included number of calves weaned, hind and offspring food consumption, stag calf and hind carcass weight and hind calf liveweight at 15 months. It was concluded that antler characteristics should be excluded from the breeding objective as they have no monetary value in the UK deer industry, but they may be included in selection criteria if they can be shown to improve the accuracy of breeding value prediction.

Sources of variation in carcass traits and weight traits were investigated using linear body measurements and photographic techniques. Heights and girths were found to be the best predictors of weight traits. Weight was found to be the best predictor of carcass composition.

Recommendations are made for future research. These include the setting up of cross breeding and selection experiments for more accurate parameter estimation and the heterotic effects of using Wapiti and animals of European parentage. Farmers are encouraged to use artificial insemination and the BDFA and MAFF are advised to set up a performance recording scheme.

ACKNOWLEDGEMENTS

Without the help and cooperation of several people this thesis would never have been completed. I would like to thank especially Dr Robin Thompson for his time and patience and for supervision of this thesis in its final stages. Thanks also to Dr Andrew Speedy for initiating the project and to Dr Peter Savill for making the move from Oxford to Edinburgh possible. I would also like to thank Linacre College, the A.J. Hosier fund, and MAFF for funding this project at various stages.

Since this project used information and collected records from several sources, I would like to thank the many farmers and research workers (too many to mention individually) who gave me access to their farms, records and animals. I would like to mention are Dr John Milne and A. Sibbald of MLURI and Mervyn Davies of Rosemaund EHF. Thanks also to Dr A. Fisher and Mr D. Elmhirst for carrying out dissections on certain animals. I would especially like to thank Alan Drescher and Alasdair Darroch for their enthusiasm and contributions to this thesis.

Although there is no longer an Agricultural Science Building at Oxford University, I would also like to acknowledge the help and support of the ex-staff and students of the above. I would especially like to thank Gillian Bendle, who is the perfect secretary and John Baker, whose contribution was much more than taking photographs. Thanks to Jo for sorting out Chapter 2 and for her friendship.

The staff and students of the Institute of Animal Physiology and Genetics Research, Edinburgh contributed so much to this thesis. Thanks are especially due to Steve Bishop, Liz Archibald and Ron Crump for their help, Karin Meyer for the use of her REML programs and to Neil Cameron for his enthusiasm, patience and support.

I would also like to thank my family for putting up with me. Especially to my mother who never pushed but always supported.

This thesis is especially for Marcio, who made it all worthwhile.

GLOSSARY

* = Probability (p) < 0.05
** = Probability < 0.01
*** = Probability < 0.001
ADAS = Agricultural Development and Advisory Service
AI = artificial insemination
b = regression coefficient
BDFA = British Deer Farmer's Association
BDPS = British Deer Producer's Society
BLUP = Best Linear Unbiased Prediction
BSE = Bovine Spongiform Encephalopathy
BW = birth weight
CDC = Cattle Data Centre
CPT = central performance test
CT = computerised X-ray tomography
cv = coefficient of variation
DC = date of calving
DCW = dead carcass weight
df = degrees of freedom
EC = European Community
FL = calf hind foot length
GB = girth at front (heart girth)
GDW = gross dead weight
GF = girth at back (abdominal girth)
GR = growth rate
HBL = height at back leg
HFL = height at front leg
h^2 = heritability
IAM = Individual Animal Model
ITE = Institute of Terrestrial Ecology
KO = killing out
LSH = length from shoulder to haunch
μ = mean
MAFF = Ministry of Agriculture, Fisheries and Food
MLURI= Macaulay Land Use Research Institute
MOET = Multiple Ovulation and Embryo Transfer
MS = Mean Square
MW = mid winter weight
NMR = Nuclear Magnetic Resonance
NS = non-significant
Φ = income/expense
P = profit
PC = principal component
Q = expense/income ($1/\Phi$)
r = correlation coefficient
R^2 = coefficient of multiple correlation
REML = Restricted Maximum Likelihood
RRI = Rowett Research Institute
σ = standard deviation
s.e. = standard error
SW = September weight
TB = Tuberculosis
TW = turnout weight
UK = United Kingdom
V = variance
wt = weight
WH = width at haunch

WS = width at shoulders
WW = weaning weight

Nomenclature

Species	Male	Female	Young
Chinese water	Buck	Doe	Fawn
Fallow	Buck	Doe	Fawn
Muntjac	Buck	Doe	Fawn
Pere David's	Stag	Hind	Calf
Red	Stag	Hind	Calf
Roe	Buck	Doe	Kid
Sika	Stag	Hind	Calf
Wapiti	Bull	Cow	Calf

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Chapter 1. Introduction

Farm incomes in the UK have come under increasing pressure due to the over-production of many agricultural commodities, challenges from the cheaper foreign alternatives and, more recently, the removal of government and European Community (EC) subsidies. As a result of falling farm incomes, there has been increasing interest in alternative enterprises which can be developed in an attempt to improve farm gross margins.

Alternative livestock enterprises have been based primarily on fibre-producing species such as goats, South American camelids, rabbits; and also meat production from rabbits and deer. Deer farming has proved popular with farmers already running conventional large animal enterprises. These enterprises have been shown to adapt to accommodate deer relatively easily. Britain also has a large wild population of deer which can provide a source of animals to stock new deer farms. A market already exists for 'wild' venison (deer meat); but the market for farmed venison is likely to expand as venison is a low-fat, high-protein meat, particularly well-suited to today's health conscious food market.

This thesis is a study of some the major factors influencing the production of farmed deer in Britain. The aim was to identify priorities for future research on farmed deer in terms of breeding and genetics and to highlight areas where the deer farming industry might benefit from controlled breeding programmes. It was necessary to identify sources of variation (both phenotypic and genetic) in the performance of farmed deer, to estimate phenotypic and genetic parameters for production traits and to identify possible breeding objectives for farmers.

This study used on-farm records of production from deer. Figure 1.1 shows the location in the UK of all private and research farms contributing data to this study. Human-cervid relationships between deer and other species of farm animal are explored/investigated in Chapter 2, with a review of the relevant literature. Chapter 3 describes a study of genetic and phenotypic parameter estimation for reproduction and production traits on a upland farm (the oldest in the UK). This was repeated using data from several other farms in the UK as described in Chapter 4. Chapter 5 presents results of the first central performance test carried out for deer in the UK. This was set up as there was previously no system whereby between-farm comparisons could be made, to assist farmers in their selection of replacement stock. Future breeding objectives for deer in the UK are defined in Chapter 6, to provide the basis for a controlled breeding programme. The use of linear body measurements to predict live animal and carcass weights and composition is investigated in Chapter 7 followed by a study of how these measurements change over time, in Chapter 8. The final chapter (Chapter 9) summarises the results presented in the thesis and how the information presented might be of use to farmers and deer breeders, as well as highlighting areas of possible future research.

Figure 1.1 Location Of Farms Contributing Animals and Data to This Thesis

where X = Glensaugh Research Farm (Chapter 3); 1 - 8 = farms contributing data to Chapter 4; A - F and 5 - 6 F= farms contributing animals to CPT (Chapter 5) and 2 = location of CPT; Y = Rosemaund EHF (Chapter 7);

Chapter 2. Man and Deer

2.1 Introduction

For thousands of years deer have been exploited by man as a food source, either by hunting or herding. In more recent times, farmers have tried to organise and domesticate the various species of deer along similar lines as more traditional farm animals like sheep and cattle. Ucko and Dimbleby (1969) describe domestication as:

'man's attempt to manage wild populations of animals which naturally form herds'

rather than by the adoption and hand rearing of young animals, which is more akin to taming. In this way, man has attempted to domesticate the deer from as early as AD65 when Columella wrote detailed instructions for the construction and design of wooden deer fences as well as for hand feeding and bottle rearing (Fletcher, 1988).

In this chapter the ecology and behaviour of deer, in relation to farming, is summarized. Human-cervid relationships are discussed. Deer farming as a commercial enterprise is introduced and on-farm management is outlined to highlight how the deer industry could benefit from a study such as this.

2.2 Deer Species and Their Uses

Deer belong to the even-toed ungulates (artiodactyla). This family has 17 genera, 40 species and 190 sub-species. All species except the two smallest have antlers which, unlike horns, are bony growths which are shed and replaced each year. Except for caribou and reindeer, only the males have antlers.

The species of deer are to be found naturalised all over the world (Lever, 1985; Whitehead, 1972) and are used as sources of both livelihood and sport (Lever, 1985; Bailey, 1988). Uses vary from country to country. Examples of such uses are shown in Table 2.1.

Rangifer *spp* are an indispensable resource for many circumpolar peoples and until recently were the only domesticated cervids in Europe (Borgdteede, 1988). Lapps in Scandinavia and tribes in northern USSR use reindeer (*Rangifer tarandus*) for riding and as draught animals (Clutton-Brock, 1981), as have peoples throughout China and eastern Asia for several centuries (Skjenneberg, 1984). The hair, hide, hooves and bones of the reindeer have been used for artefacts and clothing, while bone marrow supplied fat for food and lighting. North-American Indians and Eskimos use caribou (*R. tarandus artious*) for similar purposes, but these peoples tend to be hunters rather than herders (Skjenneberg, 1984). Elk/Moose (*Alces alces*) in eastern Siberia were used by Yakuts for riding as late as the 19th century; while in Sweden and Estonia they were used for draught and riding until the 17th century.

Table 2.1. Examples of Uses of Cervids

Species	Latin Name	Country / People	Product (Reference) Use [1]
Reindeer	*Rangifer tarandus*	Scandinavia, China and E. Asia	Riding, draught, meat, hide, milk, antlers, sinews, bone marrow (1) herded
Caribou		Eskimo	Meat (3) hunted
Sika	*Cervus nippon*	China, Korea, USSR, Taiwan,	Velvet (1) farmed
Fallow	*Dama dama*	W. Germany, New Zealand, UK	Venison, (1), (2) Farmed and hunted
Musk	*Moschus moschiferus* *M. chrysogaster* *M. syanicus*	Himalayas Himalayas and China	Musk for perfume (1) Farmed and hunted
Axis	*C. axis*	Australia	Venison (1) Farmed
Hog	*C. porcinus*	Taiwan	Venison (1) Farmed
Sambar	*C. unicolor*	Australia	Velvet (1) Hunted
		Taiwan	Velvet (1) Farmed
Rusa	*C. timorensis*	Papua New Guinea	Velvet and venison (1) Farmed
		Mauritius	Velvet and venison (1) Farmed
		Sarawak	Velvet and venison (1) Farmed
Elk/Moose	*Alces alces*	E. Siberia (Yakuts)	Riding (1)
		Sweden, Estonia	Draught and riding (1)

(1) Fletcher, 1984; (2) Hemmer, 1984; (3) Skjenneberg, 1984

While reindeer are the most common 'domesticated' cervid several other species are being or have been used by man. Genera *Mazama* and *Odocileus* have been reported to have been suckled by the South American Maya for religious purposes or meat (Fletcher, 1984). The Musk deer (*Moschus moschiferus; M. chrysogaster; M. syanicus*) provide musk perfume in the Orient. With a decrease in the population of musk deer and an increase in the price of musk these species are now being farmed, mainly in China (Fletcher, 1984).

East and South-East Asians also consume a variety of deer products as health tonics and cures for ailments (Lee and Ch'ang, 1985). Twenty eight parts of the carcass are used and believed to bring health, longevity and sexual prowess (Kong and But, 1985). Of these the 'velvet', or soft antler, has the highest monetary value. China supplies 51% of the velvet market in Korea while New Zealand supplies 27% (Yerex and Spiers, 1987). Meanwhile, in Europe, the canine teeth (tusks) are made into jewellery and hard antler is used for making ornaments, knife handles and buttons.

The hunting of many other species of deer for sport, food and trophy antlers is common practice all over the world. In Sweden the annual Moose (*Alces alces*) harvest is over 150 000 per year (Hawley, 1985), while in North America, Moose, Elk (Wapiti; *C. elaphus nelsoni*), White-tailed deer (*Odocoileus virginianus*) and Mule deer (*O. hemionus*) are hunted as a commercial enterprise (Hawley, 1985). In Alaska, USSR and Scandinavia herders manage over 3 million reindeer which produce 50 000 tonnes of venison annually (Fletcher and Luick, 1985).

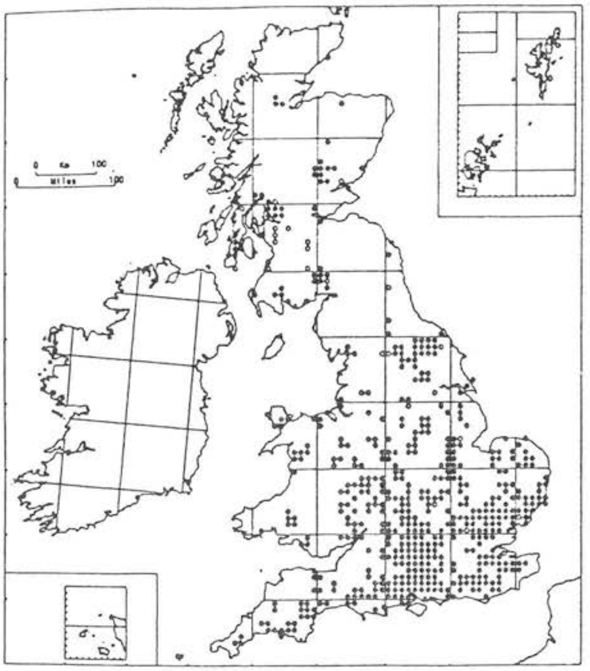
The same species can also be used for varying purposes in different countries. Sambar (*C. unicolor*), for example, are used for hunting in Australia, where they are highly prized as hunting animals but are farmed in Taiwan. The farming of deer has become more popular, especially where there is inadequate utilisation of food sources and a commercial demand for the product. Different species are used, usually depending on local availability and suitability for farming purposes.

Deer are used in attempts to increase farm incomes in a number of countries. Rusa (*C. timorensis*) in Papua New Guinea are farmed for velvet for the Asian market and for venison in the German market. They are also used in integrated farming systems with forestry and sugar cane by-products in Mauritius; while in the State of Sarawak, Rusa are used in farming of secondary scrub after rainforest felling (Kyle, 1987). Sika (*C. nippon*) are farmed for velvet production in China, Taiwan, Korea and probably the Soviet Union. In China there are an estimated 270 000 farmed sika. Axis deer (*C. axis*) are nervous, active animals but are farmed in Australia. These deer have a high frequency of twins, no well defined breeding season and can reproduce 3 times in 2 years. In Taiwan some farming of hog deer (*C. porcinus*) takes place as they also produce 3 calf crops in 2 years (Fletcher, 1984).

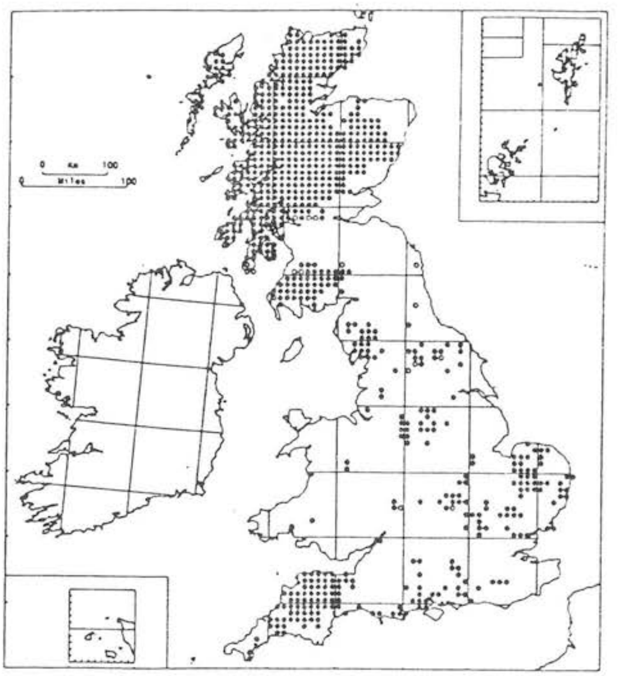
In the U.K. there are 6 species of deer of which only 2 are native (Table 2.2). The ranges of these species are shown (Figure 2.1). Most of the species were introduced into parks as decoration and for hunting purposes. The geographical occurrence of these naturalized deer in the wild is closely associated with parks where they had been introduced and subsequently escaped or been released. The Second World War resulted in the break up of many parks and the escape of deer into the surrounding countryside. Fallow deer are today the most widespread of the 4 alien species naturalized in England (Lever, 1985).

Figure 2.1 Reported Sightings of the Four Major Species of Deer in the UK

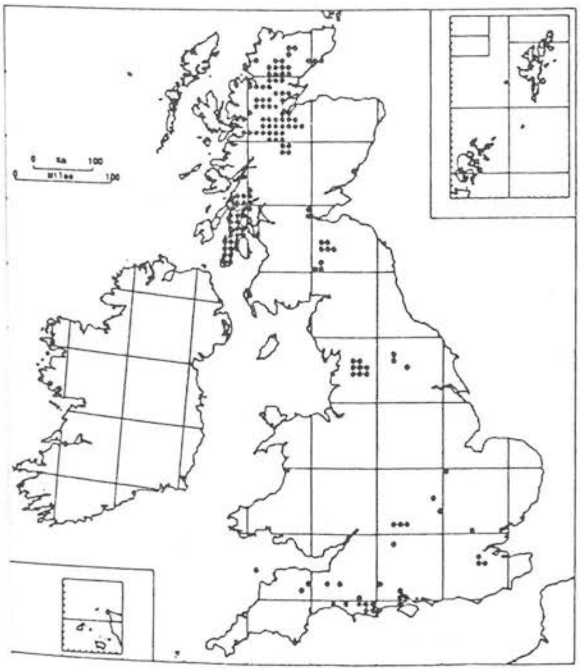
FALLOW DEER



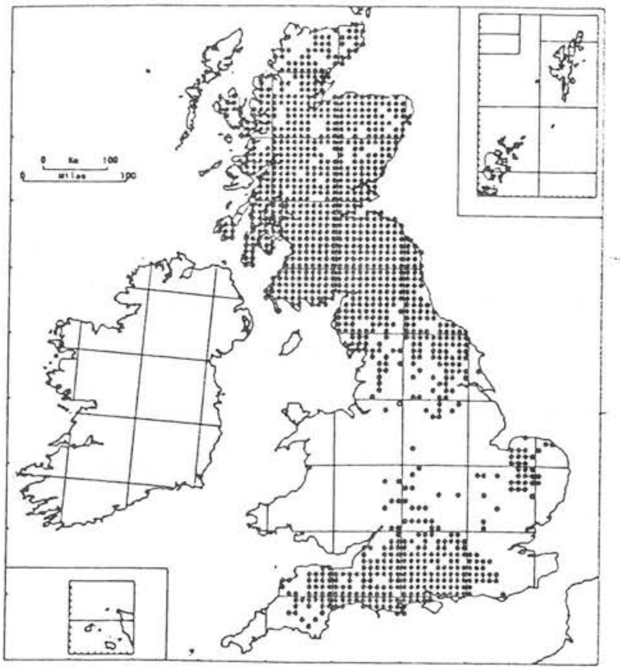
RED DEER



SIKA DEER



ROE DEER



Source: ITE, Monkswood

Table 2.2. Species of Deer in the U.K. and Their Population

[1]Red deer	*Cervus elaphus*	300,000 (290,000 in Scot)
[1]Roe deer	*Capreolus capreolus*	3-400,000
[2]Fallow	*Dama dama*	50,000
[2]Japanese sika	*Cervus nippon nippon*	10,000
[2]Reeves's muntjac	*Muntiacus reevesi*	
[2]Chinese water deer	*Hydropotes inermis*	

[1] Native [2] Naturalized (after Prior, 1987)

In the UK at present deer are used for several purposes; as ornaments for many stately homes and parks, for hunting (mainly for antlers) on many Scottish estates and some parks and wild Scottish deer are also hunted for venison. The sale of breeding stock, at home and abroad, is also a major source of income for many parks and farms. The main farmed species in the UK is the Red but some farms also stock fallow (see later).

2.3 Deer Farming

2.3.1. Introduction

Domestication of the large animal species traditionally kept as farm livestock (cattle, sheep, pigs) took over 1000 years (Hemmer, 1988). Selection for a variety of traits took place for several centuries. Deer have been domesticated relatively recently, and have therefore been subjected mainly to natural selection, with some deliberate culling by hunters and gamekeepers. Although they possess a number of characteristics which make them suitable for farming (for example their natural herding behaviour), many species possess characteristics which cause problems in traditional farming systems (for example behaviourial difficulties and, in the UK, the possession of antlers).

This section considers the suitability of different deer species for farming; and also those aspects of deer biology which influence the ways in which deer are farmed.

2.3.2. Species of Farmed Deer

The species of deer used for farming purposes vary from country to country. The range includes Rusa (*Cervus timorensis russa*) from Mauritius (Laloutte, 1985) and Papua New Guinea (Fraser Stewart, 1985), *Cervus nippon* in Korea (Kin and Han, 1985) and Fallow, Roe, Red (and their Sardinian subspecies, *Cervus elaphus corsicanus*) in Italy (Rambotti, 1985).

Not all species of deer are suitable for farming purposes. Several studies have been done both in the U.K. and elsewhere on the suitability of keeping the different species of deer for farming purposes. These studies (e.g. Reinken, 1988) have shown that Elk and Reindeer are very problematic to feed and keep under farming conditions. Roe are also unsuitable being very selective in the way they take up food and having a nervous disposition (Hemmer, 1988, Reinkein, 1988). Wapiti (*C. elaphus canadensis*) are big but have poor reproductive performance and tend to be very aggressive in fenced-in conditions. Sika are not very numerous and although studies have shown them to be suitable for farming purposes few, if any, farms stock them.

This leaves either Fallow or Red deer as the species of choice, in the Uk and most of Europe. Hemmer (1988) notes that Fallow can lead a 'balanced' life under the continuously changing and mostly crowded conditions found on most deer farms and so are suited to farming. Low fences are suitable to keep these animals together. They are social animals and show little aggression. In addition they are able to utilise fodder with a high grass content and produce higher quality meat than other species (Reinkein, 1988; Darroch, 1988; Gray, 1988). In some situations they are very prone to panic (Hemmer, 1988; Reinkein, 1988) and have a reputation for intractability and volatility when yarded (Asher *et al.*, 1988). They are also lighter than Red deer and have to be shot in the field whereas Red can be killed in a slaughter house. This will be an important factor after January 1992 when deer slaughter will have to be regulated in the same as for other farm animals. Red deer have been shown to be relatively easy to control in captivity (Hemmer, 1988). Because of this, along with the ready availability of wild replacements (Table 2.2; 2.3), Red deer have been chosen as the most popular farmed species in the UK, as well as in other parts of the world.

Table 2.3. Estimation of the Scottish Red Deer Population

Year	Nos (1000's)	Source
1900	150	Cameron, 1923
1930	250	Parnell, 1932
<1945	200	Anon, 1951
1950	100	Anon, 1951
1959	150-160	Lowe, 1961
1965	180	Stewart, 1979
1970	185	Stewart, 1985
1975	270	Stewart, 1985
1979	255	Red Deer Commission, 1980
1986	270	Stewart, 1987

Population figures after 1970 include an estimate for numbers of Red deer thought to be living in forestry plantations, before this the figures relate to open hill ground only.

2.3.3. The Biology of Deer

The natural habitat of deer is woodlands. The natural range of the animals extended south to North Africa but has diminished due to increased human population by man and deforestation. In the U.K. this led to the probable extinction of all stocks in the lowlands by the 17th century (Ritchie, 1920). Deer only survived in the highlands because of 150 years' protection for sporting purposes. Although the Scottish climate is far from ideal, the species have adapted well to living on open moorland and in the harsh conditions found there. Red deer became the most popular farmed species in Scotland not only because they are the largest in the U.K. and because of their availability (see Table 2), but also because they adapt well to a farmed situation. Scotland has become the base of the deer industry in Britain because it is the largest source of wild Red deer in the world (Fletcher, 1988).

Reproductive Behaviour

In their natural environment deer breed seasonally. This is more obvious in cold and temperate regions. Oestrus is brought about by changing climate and food supply. The pattern of photoperiod is thought to be the contributing factor to the onset of oestrus in the female (Lincoln, 1985).

The two sexes of mature Red deer tend to form separate herds except during the rutting (mating) season. The hinds and young, up to 2 years of age, of both sexes live separately from the stags. The stags join the hind herds just prior to mating. The rut generally begins in late September to early October, depending on geographical location, and lasts 2-5 weeks. Stags begin to rut and establish harems a few weeks before the hinds come into oestrus (Lincoln, 1985). The presence of the stag is thought to influence ovulation while a hind in oestrus stimulates rutting behaviour in stags. Most of the hinds conceive at first oestrus.

During this time stags cease grazing and all energy is spent on rutting behaviour. During a 2-5 week period the stag may lose up to 25% of its initial body weight (Fletcher,1986). By the 3rd week of October the large stags are emaciated and there is a decrease in rutting activity. They lose control of their harems and return to their bachelor groups. The rut ends gradually in November (Lincoln and Guinness, 1973). Interest was shown in Pere David's deer (*Elaphurus davidimus)* since they breed earlier but in experiments with them in New Zealand 30 hinds only produced one calf (Yerex and Spiers, 1987).

Blaxter *et al.* (1988) and Yerex (1979) argue that fertility of deer is weight- and not age-related. The fertility of hinds weighing 61-65kg at mating was 50% while at 70kg it was 90% (Kelly and Moore, 1977). This infers that the difference in fertility between 2 year old and older hinds reported by Bray and Kelly (1979) may be, at least in part, a function of liveweight. There is a very low incidence of twinning. Experiments carried out showed hinds were capable of conceiving twins but only single calves were born (Rhind *et al.*, 1985). Immunisation against testosterone resulted in multiple ovulation and pregnancy but both foetuses could not be sustained through pregnancy.

The polygamous nature of Red and Fallow deer suits them well to farm breeding. With single stag mating the recommended ratio is 1 stag to 30-40 hinds (Hamilton, 1986). This depends on the age of the stag and the type of terrain. A yearling stag should only have 10 hinds whereas a 6 year old could probably manage up to 60. On rough hill ground, with large enclosures and in a poor environment more stags are necessary.

Parturition

A large percentage of the farmed deer in the UK are from northern Scotland. The rut in these animals is timed so that birth occurs at the optimal time, i.e. when forage is in plentiful supply (Lincoln, 1985). The gestation period is about 231 days with the first calves being born in late May. Hinds seek solitude at calving which is thought to reduce mismothering (Fletcher, 1986). Even in farm circumstances mismothering and orphan calves are not problematic. Calving problems are rare in the wild as hinds tend not to be overweight in the Spring.

The tagging and weighing of calves at birth is a matter of great debate. The disturbance to the hinds is thought by some farmers to be considerable (Henshaw, 1989) and mismothering occurs. Others believe that tagging can be carried out with little/no problems (Gumbley, 1988). The hind that comes forward is believed to be the mother. Since calves are born in the field and calves are hidden in long grass by their mothers they can be difficult to spot. Hinds may also become aggressive at calving (Gumbley, 1988). The alternative is tagging at the autumn handling and then releasing the calf to see which hind it suckles. The task is then less laborious and animals are undisturbed at calving. It is assumed there is some mismothering but this is thought to be minimal. While neither system is perfect each has their own supporters depending on which the individual farmer. Many farmers do not match hinds to calves at all.

Weaning

Under natural conditions weaning occurs gradually at 8-10 months of age, usually as response to declining levels of nutrition. Calves closely associate with their mothers for at least a year or even for life in the case of females. Suckling results in delayed mating, later calving and decreased liveweight of hinds (Loudon *et al.*, 1983). Hamilton and Blaxter (1980) state that early weaning (at 3-4 months of age) decreases the spread of calving with no effect on fertility. The case for early weaning is supported by the fact that by 3 months calves get only 10-20% of their energy from their dam (Kay, 1985).

Delaying weaning until November resulted in an 8 day delay in calving the next year (Milne *et al.*, 1987). This difference was attributed to the effect of lactation *per se* as there was no difference in the liveweight of hinds in the early and late weaning groups. This was supported by Loudon *et al.* (1983) and continuing lactation is shown to delay calving further (Adam and Moir, 1985). This would infer that, for farming purposes, earlier weaning is more desirable as early calving enables the calves to fully utilise forage available in the summer months, especially in the lowland where grass is available earlier (Adam and Moir, 1985). This also has advantages in heavier hind weights which means they can lose more weight in the following lactation without fertility being seriously affected (Hamilton and Blaxter, 1980).

Growth

As in other species, calf growth rate is significantly and positively correlated with the milk yield of the hind (Loudon and Milne, 1985). Weaning weight was found to be an important source of variation in liveweight at 16 months of age (Milne *et al.*, 1987). Therefore, high weaning weights are desirable to achieve maximum liveweights at 16 months when animals are slaughtered and to ensure that hinds of 16 months conceive and are able to give a healthy calf at weaning the following year. The different mature liveweights and growth rates of the different species of deer have been used in selecting suitable species for farming (see later).

Crossbreeding has also been used, especially in New Zealand, to improve growth and antler characteristics of deer. The New Zealand 'Wapiti' is a hybrid of *C.e.nelsoni* and Red deer (Fennessy and Pearse, 1990). Holmes (1982) states that Wapiti grow 52% faster than Red while Wapiti cross Red grow 18% faster. Wapiti cross Red deer show growth rates that can be in excess of 700g/day (Hamilton, 1988) compared with 300g/day for pure Red (Asher and Adam, 1985). Calving rates in Wapiti tend to be somewhat lower than those for Red deer and there is some concern that calving difficulty will increase when crossed with the much smaller Red hinds.

Longevity and Mortality

The life expectancy of Red deer in the wild is about 5 years but in captivity this increases to about 20 years (de Nahlik, 1959). Natural mortality is highest in late winter and early spring (Mitchell, 1973). Stags lose much weight during the rut and so have poor reserves of fat at the onset of winter. Hinds and calves also exhibit a period of inappetance during the winter months. This phenomenon is well documented (Blaxter *et al.*, 1988; Adam and Moir, 1985; Adam, 1983; Kay, 1985). Natural mortality is also inversely correlated with shooting pressure (Lowe, 1969). This seems to infer a role of nutrition in mortality. Animals have higher growth rates in better environments. Nutritional stress results in for poor growth.

Stress may be food, exposure or population density related (Mitchell, 1973).

Antlers

Antlers are bone like structures growing from 2 raised cylindrical bones (pedicles) which protrude from the frontal bone of the skull (Harris and Duff, 1971). Whereas horns have a hard outer skin growing continuously from a soft living core, antlers are grown and cast each year. They are only found on males, except in caribou and reindeer where they are found on both sexes. In Red deer it takes approximately 3.5 months to grow a new set of antlers. This is influenced by the climate and food supply as well as age. Although some studies suggest that antler size is highly heritable others hold environmental factors to be a greater influence (Harris and Duff, 1971).

The mechanism by which photoperiod regulates antler cycles involves seasonal change in the levels of testosterone (Goss and Rosen, 1973). After the rut testosterone levels fall and antlers are cast. New growth starts immediately. The growing antler is covered by skin, known as velvet. During the spring and early summer testosterone levels increase and antler growth stops. The blood supply to the velvet is cut off , the skin dries and is rubbed off against trees and other vegetation. This can cause serious damage to trees, especially in young plantations. In New Zealand a large part of the farmers income from deer farming comes from the sale of velvet to oriental countries where it is used as an aphrodisiac. In the UK, cutting the antler before it is hard is illegal. This therefore gives a different emphasis to the production systems in the two countries.

Antlers are regarded as secondary sex characteristics. Possession of antlers is accompanied by aggression of the male in the rut. They are adapted to pushing and wrestling and are a visual display of power. The removal of the antler is necessary to avoid damage to persons or fences during the rut. Without removal of antlers any movement or handling of the deer during the rut is impossible (Korner and Winkelmann, 1988).

2.3.4 Deer Farming in Britain

While deer farming is generally regarded as a new practice, the first farms dating back to 1970, Hingston (1988) remarks that there is really nothing new about deer farming. In the past, as now, deer were kept for their meat and for hunting. The differences being that deer parks are generally ancient, walled and owned by the aristocracy while farms are modern, wire fenced and usually, but not exclusively, owned by commoners. It could also be added that Park deer were ornamental or kept to provide sport; while farmed deer are managed for profit.

The history of 'captive' deer, in the UK, has been closely associated with royal forests and parks. Most English parks were stocked with Fallow deer (*Dama dama*). Shirley (1867) notes 334 parks out of which only 31 contained Red deer (*Cervus elaphus*). Whitehead (1949) estimated approximately 10000 captive Fallow but only 2780 captive Red. The deer farmer, on the other hand, has tended to stock his farm with the Red deer. This is not only because of the more plentiful supply (see below) but because they have higher mature weights.

The Ministry of Agriculture Fisheries and Food (MAFF) defines farm deer as:

'those kept on land enclosed by a deer proof barrier for production of meat or other foodstuffs or skins or by-products or as breeding stocks for this purpose'.

In 1988 of the 252 holdings which held deer only 133 were termed farms by the above definition (Anon, 1989). In 1988, it was estimated that there was approximately 13,000 farmed Red deer in the U.K. (Milne, 1988) and 1990 estimates had risen to 35,000 (Walker, 1990), though it is not clear whether the last estimate included deer excluded by the MAFF definition.

Investigations into the possibility of farming deer began in 1970. The Rowett Research Institute (RRI) and Hill Farming Research Institute (now the Macaulay Land Use Research Institute (MLURI)) set up in a joint project in this year at Glensaugh to investigate the suitability of the species as a farmed animal and to study appropriate management practices. Most of the research work on the farmed species has been done on aspects of nutrition, health and management of deer. The findings of this project are published in two reports (see Blaxter *et al.*, 1974, 1988). The first commercial deer farm was set up in 1974 and since then numbers have increased steadily.

The original investigations were carried out for several reasons: 1) To look at ways of increasing gross margins of highland farmers. 2) To introduce a meat which accords with the present market's preference for low fat, high protein, "healthy" meat. 3)The availability of high tensile netting at reasonable price suitable for deer fencing.

1) *Income* The main farming enterprise in the north of Scotland is sheep farming. In the late 1960s, farm incomes were falling and the need arose to find alternative sources of income for farmers (Blaxter *et al.*, 1988). Deer thrive better on poor land than do sheep. All deer are at least 10% higher in dressing percentage than sheep (Drew and Hogg, 1990). There is also an unfulfilled demand for venison (and more recently for breeding stock) in Europe, so a higher price can be attained for these products. The price of venison is currently £3.00/kg dead carcass weight (d.c.w.) versus £2.00-2.50/kg d.c.w for lamb (Nix, 1990).

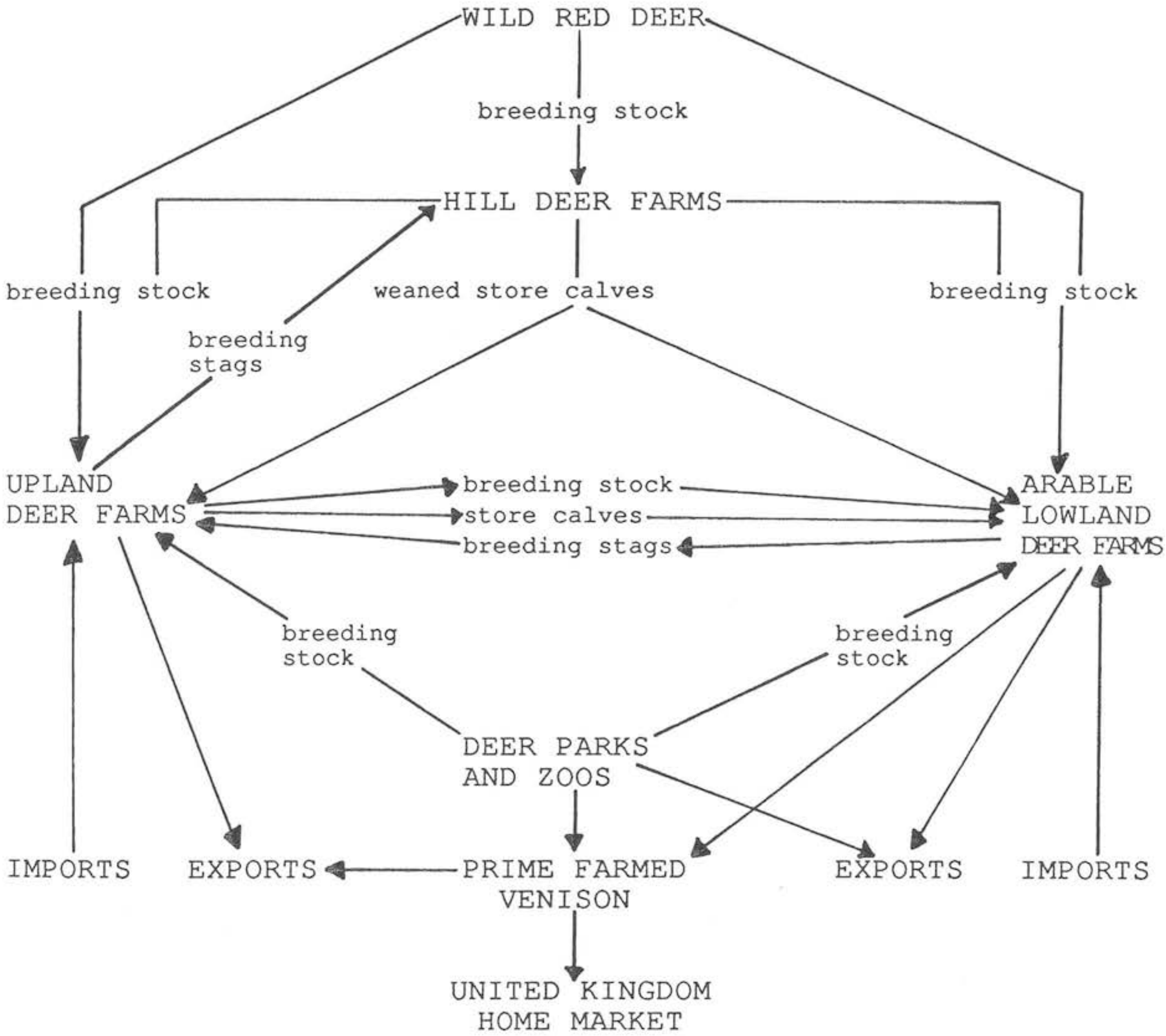
2) *Health* With the increase in western society of heart disease and obesity there is an opening for a low fat, high protein red meat. The average fat content, expressed as a percentage of carcase weight, is 22-27% for lambs, 18-22% for bull beef and 8-12% for stags (Lees-Millais, 1987). From the farmer's point of view deer are a desirable animal to farm. The dressed carcass weight of a young Red deer is 53 - 60% of liveweight (Blaxter *et al.*, 1988), which compares favourably with other farm species.

3) *Fencing* Since a large number of farm deer are captured from the wild the importance of suitable fencing cannot be overstated. Deer can jump in excess of 1.8m and so high fences are necessary to keep them under control. During the rut stags can become aggressive towards other stags, and humans. The fence needs to be able to withstand attempts of the aggressive males in neighbouring paddocks to attack each other.

More recently research into deer farming has also begun at Rosemaund Experimental Husbandry Farm in Hereford, concentrating mainly on systems of deer farming for lowland farms. Deer farming is also being taught at many agricultural colleges throughout the country (eg Sparsholt College near Winchester and Barony College near Dumfries). This increasing interest in research and teaching of aspects of deer farming reflects its increasing popularity as a farming enterprise. The industry itself is becoming stratified like the sheep or cattle industries with hind-calf producers on hill land with rearing and finishing being carried out on the lowlands (Hamilton, 1986). Figure 2.2 (and Appendix I) illustrates the stratification of the British deer industry.

Information and help about deer farming are now readily available for new entrants through the British Deer Farmers Association (BDFA) and marketing of live animals and carcasses can be done through the British Deer Producers Society (BDPS), under their "Prime Venison" label. These organisations aim to increase the profile of farmed venison as a suitable meat for today's lifestyle and to advertise the industry at home and abroad. They also attempt to highlight the difference between farmed and wild venison and promote the farmed variety as a less 'gamey' product.

Figure 2.2. The Stratification of the Deer Industry (after Hamilton, 1986)



Current Production

Precise figures for the production of venison in the U.K. are difficult to obtain because of the 'farm shop' method of selling the meat. Figures for 1988 are shown in Table 2.4.

Table 2.4. Production of Farmed and Wild Venison

Source		Production (tonnes per annum)
U.K. domestic production	-	100
U.K. wild deer	-	3000
N.Z. imports to U.K.	-	100 - 150
N.Z. total production	-	3500

(after Marlow, 1988)

The bulk of venison sold in the U.K. is from deer forests on Highland estates in Scotland (Table 2.4). The animals, which tend to be the older stags and hinds, are culled. The meat is therefore a by-product of stalking and tends to be of dubious and inconsistent quality (Gray, 1988). An examination of carcasses reported in the *Daily Telegraph* (Anon, 1988) supports this view. The deer may be dragged on the ground or on the back of a pony for several miles before getting to sterile conditions.

In the case of farmed production in the U.K., it is believed that output doubles every three years. New Zealand imports are forecast to double, at least, over the next five years. Current U.K. consumption of meat is approximately 4 million tonnes per annum. Venison production, therefore, is an infinitesimal proportion of the total meat market. The aim, therefore, is to increase venison production. Many deer farmers sell their meat at the farm gate or to local hotels or restaurants. Deer is shot in the field and dressed on the farm. More recently considerable numbers of deer are now being slaughtered in abattoirs and venison sold in the supermarket.

By the end of 1992 the trade barriers between the member states of the EC will be dismantled therefore increasing the 'home' market. The need for an integrated slaughtering system with records relating breeding and slaughter animals is needed for the industry to survive and expand beyond its present status of a 'cottage industry'. In New Zealand 10% of farmers farm deer as against 0.001% in the U.K. (Fletcher, 1987). Because of the high production levels and a lucrative import/export trade, what happens in New Zealand will have a large effect on what happens in the U.K.

2.3.5 Deer Farming in New Zealand

In New Zealand Red deer are the most recently introduced and the most widely distributed large animal (Lever, 1985). The species was first introduced in 1851 and between then and 1926 some 220 separate liberations were recorded involving more than 820 animals (Logan and Harris, 1967). Due to the absence of natural predators, a suitable climate and the abundance of food, the species thrived. Red deer were also protected from shooting until 1890. Several authors (Cockayne, 1926; Zotov *et al.*, 1939; Yerex, 1979) note that the species soon multiplied to such a degree that it became 'the most destructive alien species in New Zealand'; the damage to woodland and farming only being rivalled by that caused by rabbits.

Farming in New Zealand arose as a way to alleviate the problem caused by the deer. It is also a way of ensuring a sufficient, regular, continuous supply for the German venison market, previously supplied by the game exporters (Yerex, 1979). This coupled with the market for antler velvet (used for medicinal purposes in the Orient) and the growing demand for venison soon led to a rapid expansion of deer farming in that country. In the late sixties and early seventies the New Zealand government financially encouraged the culling of deer. This led to deer being shot from helicopters but entrepreneurs decided that the farming of the animals would make more financial sense.

Eighty-five percent of deer farms in New Zealand were established from farms carrying traditional livestock species (Gladden, 1981). In 1983 it was estimated that there were 240,000 farmed deer in New Zealand (Milne, 1988), while in 1987 (Rapley, 1988) there were over 500,000. In 1985 (Moore *et al.*, 1985) Red deer was the most popular species (84% of the population), followed by Fallow (14%) and Wapiti (1.7%) but by 1987 79% were Red, 12% Wapiti/Canadian Elk, 8% Fallow and 1% other (Rapley, 1988).

The marketing of farmed venison in New Zealand is done by companies already selling game venison. This, coupled with tax incentives for investors, low profits in the other pastoral enterprises and the fact that harvesting of antler velvet is permitted in New Zealand has let to a rapid expansion of the industry. This process is banned in the UK because, when in velvet, the antler is a growing tissue with a copious blood supply and cutting the antler at this stage is deemed to be cruel to the animals. The success of the industry, in New Zealand, has also been helped by the building of 7 specialised abattoirs to ensure hygienic and proper slaughtering practices. Similar developments, but on a smaller scale, are taking place in Australia.

2.3.6. Deer Farming in Continental Europe

Several countries in Europe are now starting to develop a deer farming industry. Such industries tend to be based on Fallow rather than Red deer, reflecting the most widely available local species in those countries. There is much interest in Germany and Scandinavia but legal and other constraints presently restrict the rapid spread of the industry. The industry in (what used to be) West Germany is based on Fallow deer. In 1987 there were an estimated 2,000 farms with 40,000 does (see Glossary). Only a few farms stock Red deer.

The first Belgian deer farm was established in 1988 (van Beuningen, 1988). It is estimated that the country has 4-6000 Red deer and 50-100 free-living fallow. Deer farming in Denmark started in 1980. Now the Danish Deer Farmers' Association has approximately 450 members and 300-350 farms. Legislation limits the species on deer farms in Denmark to either Fallow or Red (Vigh-Larsen, 1988). Fallow is the most common farmed species with 10-12000 does in 1987. There are about 2000 farmed Red deer in Denmark.

2.4 Deer Breeding and Genetics

2.4.1 Introduction

The profitability of deer farming at present is highly dependent on the sale of hind calves. In 1987 lowland farmers could expect between 23% return on their investment (Hutchinson, 1987) while in 1990 this has fallen to an average of about 14% (Cordery and Nix, 1990). In recent months the scare of bovine spongiform encephalopathy (BSE) spreading to deer has depressed the export market and with high interest rates depressing the home market gross margins look less favourable. For farmers to maintain their income the performance of the meat side of the enterprise should become more prominent.

While in the short term better management practices will help to improve production characteristics, in the long term the selection of animals which will produce superior offspring is necessary. Provided selection is maintained, genetic improvement is permanent and cumulative. But, to date, there has been no formal definition of breeding objectives for deer in the U.K.. Even in New Zealand, with larger herds, data is somewhat limited (Rapley, 1990). Selection of replacement animals is somewhat haphazard, the most popular method being to choose the stag calves which are 'biggest' at the rut (at 15 months of age). Since many farmers have no weighing scales this is often purely a subjective assessment. No account is taken of birth date, as this is frequently not known.

In some respects deer are similar to other farm animals. They are seasonal breeders (like sheep) which tend to have one calf per year (like cattle). There are other aspects of deer production which make deer unique as a farm animal. For example, deer are the only species to have antlers. Selection has been carried out on other species of animals (pigs, sheep, cattle) for several centuries, for several different traits. The recent domestication of deer means that they have been subjected mainly to natural selection (and some culling by game keepers and hunters). A genetic study of several aspects of deer production is therefore necessary and is likely to benefit both the farmer and the industry.

2.4.2. Sources of Breeding Stock

Due to deforestation the natural woodland habitat of these species has been eroded. The Red deer in particular has managed to adapt well to living in open ranges of the highlands of Scotland. The elimination of the natural predators of the deer (wolf, bear and lynx), decline of hunting and low human population density has meant the species has proliferated and careful management of stocks is needed (Prior, 1987b). Wapiti have, from time to time, been introduced into some Scottish deer forests to improve the head quality of the native Red (Lever, 1985).

The Scottish Red tends to be smaller than those found further south or Park Red (Table 2.5). This is due to poor nutrition, energy expended in movement up and down hills and possible inbreeding. Suttie (1980a, 1983) studied the effect of nutrition on growth rates and the size of antlers and found that when Scottish stags were fed *ad libitum* both grew as well as those from lowlands.

Table 2.5. Mature Weights of Red Deer

Species	Source	Sex	Mature weight (kg)
Red	Scottish Hill[1]	M	95
Red	Scottish Hill[3]	M	94
Red	Scottish Hill[3]	F	51
Red	U.K.[2]	M	90-190
Red	U.K.[2]	F	57-115
Red	English Woodlands[1]	M	189
Red	E. European Woodlands[1]	M	255

[1] Southern, 1964; [2] Prior, 1987; [3] Whitehead, 1960

Since the deer industry is still expanding, and likely to do so for many years, there is a need to supply this expansion with hinds from several different sources. Initially most of the farmed deer in the U.K. were captured from the wild. It is thought that, at present, 2 000 hinds are being removed annually from the wild (Fletcher, 1988) but progressively more farms are being stocked or getting their replacements from other farms. The number of wild hinds captured is likely to increase since the market price for live hinds (for breeding) is substantially higher than the venison price.

Deer parks in the U.K. were set up by the Normans for hunting and as a major source of food (Gray, 1988). The management of deer parks or wild deer has generally been concerned with, in part, the production of fine heads of antlers for trophy hunting. This characteristic is thought to be heritable but nutrition is known to play a significant role here. There are now 150-200 deer parks in the UK. Their purpose over the last 200 years has been more for amenity than food.

Park deer are now being sold as breeding stock for deer farms, their prices in many cases substantially higher than those from other sources being of a perceived higher quality. Red deer are also being imported from countries of Eastern Europe (e.g. Hungary, Yugoslavia, Czechoslovakia and (what used to be) East Germany) where they live naturally in forests. These animals tend to have higher mature weights (Table 2.5) and farmers are planning to use them for crossbreeding with native British Red deer.

There are separate stocks of deer used for farming purposes, those from Scottish hills, English parks as well as European forests. The question arises as to which of these types of animal are more suited to the different layers (production of dams, sires, animals for crossbreeding) of this industry and are the animals from different sources genetically different from each other. Red deer, in their natural habitat, from different sources show large variation in size (Table 2.5).

2.4.3. Relevant Production Characteristics and Selection Criteria

Performance

Growth of deer, and male deer in particular, is highly seasonal. They gain weight rapidly in the spring/summer and lose most of their fat during the autumn/winter (Drew, 1985). The genetic effect of inappetance on calf growth over the autumn/winter period needs to be investigated. Crawford (1990) states that larger, earlier born calves tend to 'mark time' whereas younger ones tend to have higher growth rates. The inappetance is thought to be due to weather stress rather than nutrient availability, as well as Yeraniosis (a stress related bacterial disease) (Milne, 1988). Selection for animals which are genetically less likely to lose weight during the winter is desirable.

If farmers cannot sell their stags calves at 15-18 months of age they will then be affected by the inappetance effects noted above. Farmers will also need to have a supply of silage or hay to keep these animals for a second winter. The importance of getting hind calves to an adequate weight for breeding was discussed earlier in this chapter.

Breeding and Reproduction

The success of a breeding herd depends on the calving and weaning percentages. When calves weighed less than 4kg, mortality was 100% but at 7-8kg mortality fell to 5% (Milne, 1988). Birthweight and the factors which influence it are important in the production of deer. The rut and calving need to be timed so that calves are born when the grass supply is plentiful to support the lactating hind. In the lowland, more grass is available earlier than on the Scottish hills to which deer have become adapted. Farmers on these farms, therefore, want hinds and stags to breed earlier. Hinds usually conceive to first oestrus (Milne, 1988) therefore selection for hinds which come into oestrus earlier is desirable. Since oestrus is not observed it is necessary to examine the possibility of selection on calving date.

At present deer farmers are keeping their hinds for up to 15 years (or for as long as they will breed) and stags for up to 8 years. This means that any genetic progress will be slow as generations are long and selection intensity low. While a number of studies have investigated the use of artificial insemination in deer (Krzywinski and Jaczewski, 1978, Haigh, 1984; Haigh *et al.*, 1984; Magyer *et al.*, 1989) numbers of calves produced have, in general, been small. The success of artificial insemination is still poor, 40-50% for cervical insemination, and while laproscopic (intra-uterine) insemination is better (65-86%) the cost is prohibitive (Bowen, 1988). To date no genetic comparisons between different farms have been carried out. Methods of between farm comparisons can help farmers increase selection intensity and make faster genetic progress.

Temperament

The rut is a form of breeding behaviour unique to deer. The development of antlers and aggressive behaviour in the male make it desirable to select animals which are of good temperament. Once deer have lost their fear of man they can be very dangerous (Fletcher, 1981). This is especially true during the rut. Stags in neighbouring paddocks can easily destroy fences. Even-tempered hinds which will allow their calf to be handled (and tagged) at birth and will not abandon their calves when handled by humans. Temperament is also important since routine medical treatments, TB testing and antler removal have to be carried out.

Antlers

Antlers, in terms of production in the UK, are superfluous, having no market value. Selection of breeding stags is frequently carried out on the basis of the size of antlers at 15 or 27 months of age. This is due, in part, to breeding advice coming from New Zealand where the sale of antlers forms a major part of the gross margin of the enterprise (see earlier).

Carcass

Farmers desire an animals with a high percentage of meat in the areas of the carcass which has a high monetary value, mainly in the hind quarter. Selection of these animals is based on a visual assessment of 'conformation' which is highly subjective and the accuracy of this assessment depends on the experience and expertise of the assessor. A more objective, but simple for on-farm use, method of scoring these animals is desirable. An assessment of the fat in the carcass is also desirable, if only for reference purposes. Variations in size and shape of the animals, and how these relate to carcass meat production is another aspect which farmers are interested in, as well as changes in these as the animal grows.

2.5 Summary/Conclusions

Deer farming in the UK is only 20 years old yet much research has been made to investigate suitable management systems and has tended to concentrate on aspects of nutrition and health of farmed deer. To date no investigation into the genetic aspects of deer farming in the UK has been carried out.

This study aims to examine some phenotypic and genetic aspects of production and reproduction in farmed red deer, and the production of venison. This involves the identification of suitable breeding objectives, the estimation of phenotypic and genetic parameters for production traits and to highlight areas where research in deer farming could be concentrated. Since most entrants are relatively new the availability of on-farm performance records tends to be limited. Despite this, the estimation of genetic parameters will be relatively free from bias since the main criteria for selection (especially in hinds) is survival.

Chapter 3. Estimation of Genetic and Phenotypic Parameters for Growth and Reproductive Traits on an Upland Farm

3.1. Introduction

Deer farming was originally intended as a means of improving gross margins for hill farmers in Scotland (Blaxter *et al.*, 1988). The deer industry is now becoming stratified like the sheep industry, with hind-calf producers in hill and upland areas, while fattening is mainly carried out on lowland farms (Hamilton, 1986). Much work has been done by the Macaulay Land Use Research Institute (MLURI) and the Rowett Research Institute (RRI) to develop suitable management systems for deer (Blaxter *et al.*, 1974, 1988). To date, no estimates of genetic parameters are available for farmed deer in this country.

Knowledge of genetic and phenotypic parameters is necessary to calculate selection criteria which optimise the rate of genetic improvement for given selection objectives for a given animal production enterprise, and to enable farmers and breeders to make objective selection decisions. The aim of this chapter is to estimate phenotypic and genetic parameters for traits measured throughout the life cycle of an unselected population of Red deer in a relatively harsh environment in the north east of Scotland.

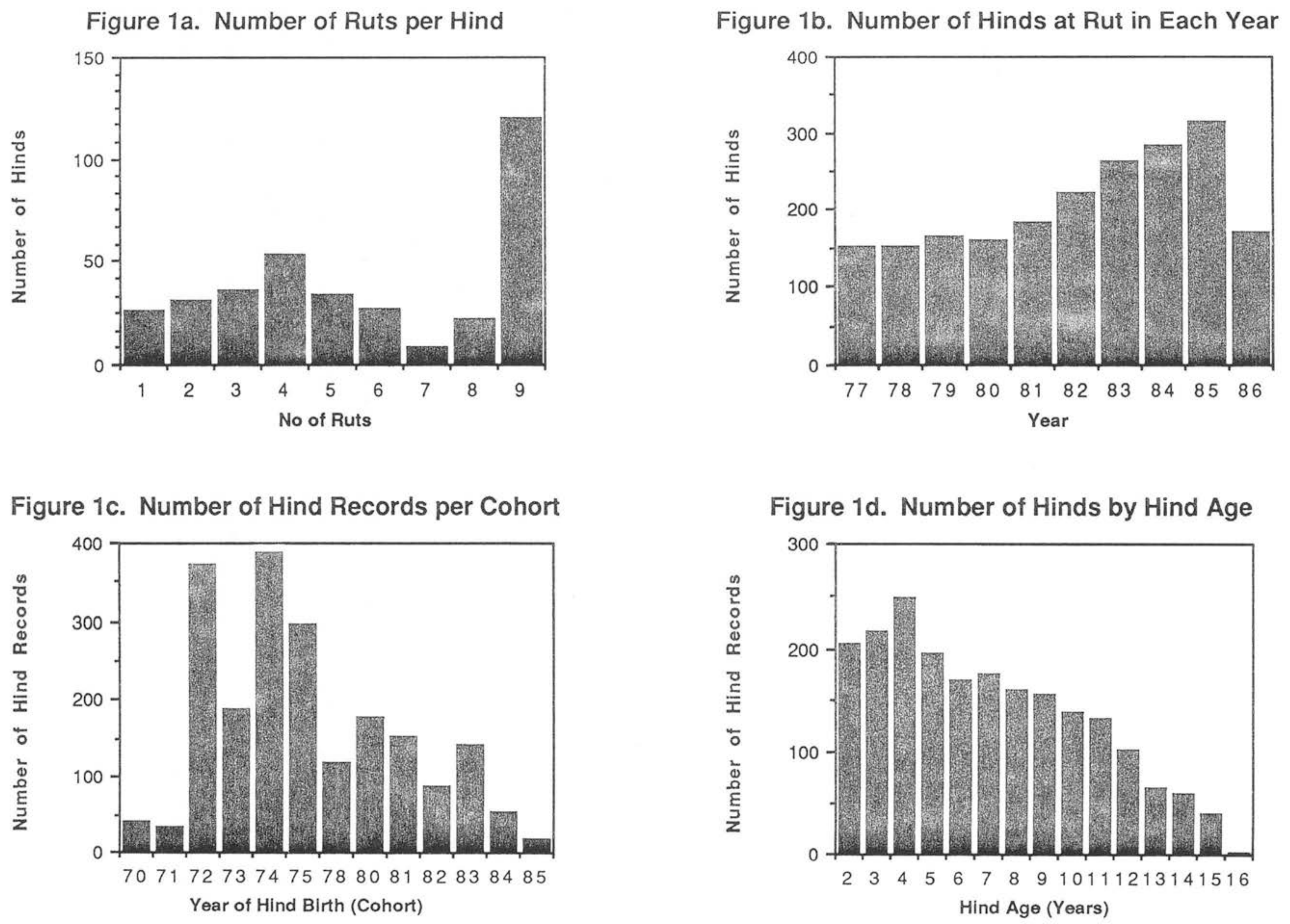
3.2 Materials and Methods

3.2.1 Introduction

Deer farming in the UK is only 20 years old, with the first herd being established in 1970 by the Hill Farming Research Organisation (now the Macaulay Land Use Research Institute) at Glensaugh, in Kincardineshire near Aberdeen. The production system developed at Glensaugh up to 1980 reflected an upland farming system. In recent years more lowland farmers have taken up deer farming and so, from 1980, a proportion of hinds were grazed on reseeded pastures at Glensaugh in the summer.

The data for this study came from hinds put to the stag between 1977 to 1986 inclusive. In total, 2069 records were available, a summary of which is given in Figure 3.1. Of these records, 430 had the sire identified. From Figure 3.1a it can be seen that the distribution of number of ruts per hind is heavily skewed, a large number of hinds being kept for 9 years. Examination of the accompanying histograms indicate the reason for this. Figure 3.1c shows that a number of animals from the earlier cohorts (72-75) accounted for a large proportion (0.60) of the records, while records for cohorts born in years 76-19 were not available (except for a small number born in 1978). Some of these cohorts were used for experimental purposes and these animals were not replaced (see Blaxter *et al.*, 1988). Hinds were kept for up to 16 years of age, with herd numbers being built up.

Figure 3.1. Distribution of Hind Records by (a) Number of Ruts, (b) Year of Rut, (c) Cohort and (d) Hind Age at Calving



3.2.2 Herd Management

Full details can be found in two reports describing the management systems used at Glensaugh (Blaxter *et al.*, 1974; 1988). A brief summary follows. Deer are seasonal breeders, the rut (breeding season) commencing in October. Hinds were divided into rut groups in September with one or more stags. In the early years multiple sire mating was the norm while single sire mating was practised in later years. With single sire mating, the stag was left with the hinds for a period of 5 to 6 weeks after which hind groups were mixed, with more than one stag per group. It is therefore sometimes difficult to identify the sire, although studies show that most hinds conceive to first or second oestrus (Hamilton and Blaxter, 1980).

Calving generally occurs in June, with hinds either on hill or upland pastures. Hinds were offered supplementary feed for up to 2 months before calving on the hill, but no supplementary feed was offered to hinds on upland pastures. Calf weight (BW; kg), date of birth and in some cases hind foot length (FL; cm) of calf at birth (a measure of skeletal size) were recorded. Calves were also matched to hinds at this stage. Calves were generally weaned in September (when the remaining offspring-dam pairs were matched up) and housed over the winter. For experimental purposes, some calves were weaned in January, in one year. Over winter the calves were fed hay, silage and a small amount of concentrates. Hinds were outwintered and fed hay when foraging became difficult. Calves were turned out to pasture in

April/May, at 10 months of age.

In most years calves were not kept beyond weaning or turnout and so data for post-weaning traits is limited. Selection for breeding and slaughter took place at 15 months of age. Calves were weighed at weaning (WW; kg), turnout (TW; kg) and September (SW; kg). Growth rates from birth to weaning (GRBW; kg/day), weaning to turnout (GRWT; kg/day) and turnout to September (GRTS; kg/day) were then calculated. Hinds were weighed four times during the year - pre-rut (September), December, February and April.

3.2.3 Statistical Analysis

Each trait was analyzed using all the available records. The traits naturally fell into groups. These groups were calf pre-weaning traits, calf post-weaning traits and traits measured on the hind. The traits were analyzed to identify the most important effects so the most appropriate model could be fitted for each trait/group of traits. Non-significant ($P > 0.10$) effects were successively omitted from the models and the reduced models were fitted for each trait. Effects fitted included sex of calf, dam age, year of rut, proportion of Wapiti parentage in the calf, location of the calf post weaning (hill or upland) and location of hind pre weaning. Covariates included age of calf at weighing and date of birth of calf. Part of the herd was on a number of experiments during the years for which data was available. A total of 401 calves were in 42 experimental groups and 519 hinds in 39 experimental groups (some hinds were on experiment in more than one year). Some experiments were confounded with other effects (eg type of rearing); those that were not were also fitted in the model.

All traits were analyzed using Restricted Maximum Likelihood (REML) procedures (Meyer, 1985) with a dam model and all known pedigrees accounted for. This procedure calculates the heritability that would give the greatest likelihood of getting the observed phenotypic values of all individuals in the data. The model used in all cases was a linear model with fixed effects and random dam effects. Quadratic regression coefficients were fitted but found not to be significant in all cases. Correlations were estimated between pairs of traits using the most appropriate model for each pair. Iterations were assumed to have converged when the maximum proportional difference in genetic variance components on the canonical scale was less than 10^{-5} between iterations. In general, the final model fitted for pre- and post-weaning traits was:

$$Y_{ijklmno} = \mu + d_i + s_j + h_k + y_l + w_m + b_1 x_{ijklmn} + e_{ijklmno}$$

where μ is the population mean, $Y_{ijklmno}$ is the phenotypic record of the animal, and d_i, s_j, h_k, y_l, w_m, $b_1 X_{ijklmn}$ are the random effect of the *i*th dam, the fixed effects of the *j*th sex of calf, *k*th hind age, *l*th year of record, *m*th proportion of Wapiti parentage of the calf, the regression of Y on the age of weighing and the random environmental effect associated with the record respectively.

The calving record for hinds in a particular year was coded to reflect whether hinds were barren, whether the calves died perinatally or survived to weaning. The traits were scored to reflect whether the hind calved (1) or not (0) and, in a second analysis, whether the calf survived to weaning (1) or not (0). Repeatabilities for dam liveweights, date of calving and calving record were measured using the same model and these repeatabilities were dissected into heritability and general environment effect using Derivative Free Restricted Maximum Likelihood (DFREML) procedures (Meyer, 1989), fitting the effect of dam as an uncorrelated random effect. The final model fitted for these traits was, in general:

$$Y_{ijklmn} = \mu + d_i + p_j + h_k + y_l + w_m + e_{ijklmn}$$

where μ is the population mean, Y_{ijklmn} is the phenotypic record of the animal, and d_i, p_j, h_k, y_l, w_m and e_{ijklmn} are the random effect of the *i*th dam, the fixed effects of the *j*th previous calving record of the hind, *k*th hind age, *l*th year of record and *m*th proportion of Wapiti parentage of the calf and the random environmental effect associated with the record respectively.

Heritability estimates obtained were transformed from the binomial to an assumed underlying continuous normally distributed scale (Robertson and Lerner, 1949). The transformation used was $h^2_n=h^2_b[p(1-p)z^2]$; where h^2_n is the heritability on the normal scale; h^2_b is the heritability on the binomial scale; z is the ordinate of the standardized normal distribution at the threshold point corresponding to p; and p is the incidence, the proportion of hind showing the trait.

3.3 Results

A summary of calf traits and covariates examined is given in Table 3.1.

Table 3.1. Summary Statistics for Traits and Covariates Measured on Calf

	μ	σ	cv	No. Rec.
BW[1] (kg)	7.86	1.25	15.9	1082
WW (kg)	38.91	7.01	18.0	1082
TW (kg)	55.61	9.61	17.3	532
SW (kg)	73.42	10.20	13.9	429
Pre-rut weight (kg)	82.32	9.49	11.5	1082
FL (cm)	25.56	2.45	9.6	780
GRBW (kg/day)	0.29	0.05	18.1	1082
GRWT (kg/day)	0.07	0.04	53.0	532
GRTS (kg/day)	0.13	0.05	35.0	429
Day of birth	8 June	13.01	34.1	1082
Age WW (days)	108.85	18.59	17.1	1082
Age TW (days)	338.86	14.52	4.3	532
Age SW (days)	471.00	37.48	8.0	429

[1] BW = birth weight; WW = weaning weight, TW = turnout/April weight; SW = September weight, FL = calf foot length, GRBW = growth rate birth to weaning, GRWT = growth rate weaning to turnout, GRTS = growth rate turnout to September

Liveweight gain of calves is seen to be highest from birth to weaning (0.29 $\pm$ 0.05 kg/day). From weaning to turnout the growth rate decreases (0.07 $\pm$ 0.04 kg/day) and rises again when animals are put out to grass (0.13 $\pm$ 0.05 kg/day). All traits show a high coefficient of variation, from 9.60% for FL to 52.98% for GRWT. Coefficients of variation are similar order for all weights (13.89% to 18.02%) but differ markedly for growth rates (18.07% to 52.98%).

3.3.1 Pre-weaning Traits

Traits measured before/at weaning included birth weight (BW), hind foot length (FL), growth rate from birth to weaning (GRBW) and weaning weight (WW). Levels for fixed effects, covariates and their standard errors are given in Table 3.2 with significance levels of all factors in Table 3.3. All traits were treated as traits of the individual rather than of the hind.

Sex, age of dam and proportion of Wapiti parentage were significant sources of variation ($P < 0.01$) for all traits. Males were heavier, grew faster and had larger skeletons at birth (as measured by FL) than females. Dams of less than 4 years of age had calves of lower birth and weaning weights and their calves tended to grow more slowly than calves of older hinds. Calves of a higher proportion of Wapiti parentage grew faster and were heavier at all stages ($P < 0.01$). BW and age at weaning had highly significant direct effects on WW.

Hinds which were heavier at the rut tended to produce heavier calves which grew faster ($P < 0.01$). Heavier animals also tended to be born earlier and have higher weaning weights. Animals which were heavier at birth and older at weaning tended to have heavier weaning weights.

Table 3.2. Least Squares Means and Deviations for Fixed Effects and Covariates for Pre-Weaning Traits

	BW (kg)	WW (kg)	FL (cm)	GRBW (kg/day)
Sex Female	7.62	38.62	25.27	0.284
Male	0.41 (0.06)	3.25 (0.32)	0.55 (0.15)	0.026 (0.003)
Dam Age 2	6.62	32.65	23.74	0.252
3	0.62 (0.19)	1.23 (0.93)	0.61 (0.44)	0.017 (0.009)
4	1.30 (0.21)	2.35 (1.03)	1.09 (0.48)	0.024 (0.010)
5	1.32 (0.22)	2.91 (1.06)	1.26 (0.50)	0.028 (0.010)
6	1.19 (0.23)	1.72 (1.12)	3.83 (0.52)	0.025 (0.011)
7	1.30 (0.22)	2.25 (1.05)	3.69 (0.49)	0.037 (0.010)
8	1.41 (0.22)	3.24 (1.08)	1.27 (0.50)	0.032 (0.011)
9	1.09 (0.22)	2.80 (1.07)	2.55 (0.50)	0.025 (0.011)
10	1.18 (0.22)	3.87 (1.06)	3.94 (0.49)	0.045 (0.010)
11	1.36 (0.23)	3.39 (1.12)	1.79 (0.53)	0.027 (0.011)
12	1.09 (0.24)	3.99 (1.16)	1.33 (0.54)	0.012 (0.011)
13	1.53 (0.24)	3.97 (1.17)	1.46 (0.55)	0.008 (0.012)
14	1.63 (0.28)	4.03 (1.34)	0.96 (0.63)	0.029 (0.013)
Proportion Wapiti 0	7.74	39.84	25.49	0.292
0.25	0.77 (0.17)	3.18 (0.83)	0.17 (0.38)	0.017 (0.009)
0.50	1.52 (0.17)	5.84 (0.81)	0.38 (0.38)	0.037 (0.009)
Pre-Rut Weight	0.06 (0.02)	0.16 (0.08)	0.03 (0.01)	0.009 (0.002)
BW	-	1.83 (0.20)	-	0.008 (0.001)
Age WW	-	0.17 (0.01)	-	-.001 (0.000)
Day of Birth	-.12 (0.02)	-.31 (0.02)	0.04 (0.01)	0.009 (0.001)

BW = birth weight, WW = weaning weight, FL = hind foot length, GRBW = growth rate from birth to weaning

Table 3.3. Mean Squares, Significance Levels for Pre-Weaning Fixed Effects and Covariates

	BW	WW	GRBW	FL
Sex	44.44	2494.59	0.138	52.53
Dam Age	9.76	192.64	0.010	13.56
% Wapiti	67.36	459.33	0.043	67.95
Pre-Rut Weight	49.27	2152.48	0.036	29.69
Day of Birth	6.95	2160.45	0.045	10.85
Rear Type	-	5.97	0.000	-
Hind Location	0.46	555.46	0.010	1.03
Age at WW	-	6033.00	-	-
Residual MS	1.47	28.65	0.003	4.39

BW = birth weight, WW = weaning weight, GRBW = growth from birth to weaning, FL = foot length, MS = mean square

During the summer Glensaugh hinds were grazed on either upland or hill pasture. Calves of hinds on upland grew better and were heavier than calves on the harsher hill land ($P < 0.01$). This is probably due to better nutrition and shelter. Rearing type (natural vs artificial) had no significant effect on GRBW or WW. Experimental group was overall not a significant effect ($P < 0.05$) for pre-weaning traits.

Heritabilities, phenotypic and genetic correlations for pre-weaning traits are shown in Table 3.4. Heritabilities of pre-weaning traits are low to moderate (0.02 - 0.27). Phenotypic correlations between FL and all other pre-weaning traits are moderate (0.14-0.49), except that with BW (0.98). Genetic and phenotypic correlations between BW and other pre-weaning traits were moderate but high between WW and GRBW (0.92).

Table 3.4. Heritabilities (on diagonal), Genetic (below diagonal) and Phenotypic (above diagonal) Correlations for Pre-Weaning Traits

	BW	WW	GRBW	FL
BW	**0.27** (0.04)	0.35 (0.03)	0.19 (0.04)	0.49 (0.03)
WW	0.52 (0.10)	**0.21** (0.04)	0.82 (0.01)	0.25 (0.03)
GRBW	0.45 (0.12)	0.92 (0.04)	**0.15** (0.04)	0.14 (0.04)
FL	0.98 (n.e.)*	0.50 (0.21)	0.17 (0.27)	**0.02** (0.01)

* n.e. = not estimable; standard errors in brackets BW = birth weight, WW = weaning weight, GRBW = growth from birth to weaning, FL = foot length, MS = mean square

Post-Weaning Traits

Traits measured on calves after weaning included turnout weight (TW), September weight (SW), growth rate from weaning to turnout (GRWT) and growth rate from turnout to September (GRTS). Fixed effects and covariates for post-weaning traits are given in Table 3.5, with mean squares and significance levels in Table 3.6. While the influence of dam age remains at turnout ($P < 0.05$) this had disappeared by the September weighing. Sex and proportion of Wapiti parentage of calf remained significant sources of variation ($P < 0.01$) throughout the life of the calf.

The weight at previous weighing was an important source of variation ($P < 0.01$) for each weight trait. Generally, a heavy calf at the previous weighing maintained its weight advantage.

Table 3.5. Least Squares Means and Deviations for Fixed Effects and Covariates for Post-Weaning Traits

	TW (kg)	SW (kg)	GRWT (kg/day)	GRTS (kg/day)
Sex Female	52.94	68.01	0.059	0.111
Male	5.03 (0.60)	8.26 (0.75)	0.016 (0.003)	0.035 (0.004)
Dam Age 2	49.00	65.50	0.037	0.125
3	5.31 (3.57)	7.26 (5.00)	0.046 (0.029)	0.000 (0.000)
4	5.14 (3.55)	4.27 (4.94)	0.046 (0.029)	0.013 (0.027)
5	3.40 (3.54)	5.54 (4.92)	0.037 (0.029)	-0.011 (0.026)
6	4.14 (3.52)	5.66 (4.92)	0.039 (0.028)	-0.015 (0.027)
7+	4.18 (3.53)	5.64 (4.94)	0.039 (0.028)	0.004 (0.027)
Prop. Wapiti 0	55.17	72.78	0.066	0.129
0.50	20.37 (1.63)	20.27 (1.72)	0.075 (0.008)	0.028 (0.013)
Prerut Wt	0.04 (0.04)	0.14 (0.04)	0.001 (0.004)	0.000 (0.000)
Age TW	0.46 (0.05)		-	0.001 (0.000)
Age SW	-	0.04 (0.03)	-	-

TW = turnout weight, SW = September weight, GRWT = growth rate from weaning to turnout, GRTS = growth rate from turnout to September

Table 3.6. Mean Square, Significance Levels for Post-Weaning Fixed Traits and Covariates

	TW	SW	GRWT	GRTS
Sex	3107.57	7252.65	0.026	0.082
Dam Age	222.23	89.37	0.001	0.003
Prop. Wapiti	5723.20	8284.72	0.138	0.007
Pre-rut Weight	91.24	2649.90	0.000	0.001
Age WW	-	-	0.013	-
Age TW	318.41	-	-	0.016
Age SW	-	98.24	-	-
WW	4458.92	-	0.061	-
TW	-	-	-	0.019
Calf Location	39.37	72.38	-	0.002
Rear Type	66.89	-	-	-
MS Residual	65.57	117.56	0.001	0.002

TW = turnout weight, SW = September weight, GRWT = growth rate from weaning to turnout, GRTS = growth rate from turnout to September

The weight at previous weighing was an important source of variation ($P<0.01$). Generally a heavy calf at the previous weighing maintained its weight advantage. Age of dam tended not to be significant ($P>0.05$) for post weaning traits, except for TW ($P<0.01$), while year of rut was significant ($P<0.01$). Age at weighing had a significant effect on TW ($P<0.05$) but not on SW. Overall, calf experiment groupings had no significant effect ($P>0.05$) although those calves on higher feed levels did show higher solutions for fixed effects when compared with those on lower feeding regimes. The effects were highest when winter feeding levels were being examined.

Weights at different ages were genetically highly correlated with each other (Table 3.7). All post-weaning growth traits had a lower heritabilities than pre-weaning traits. TW had a lower heritability (0.10 ± 0.05) than the WW or SW and GRWT had a correspondingly low heritability (0.08 ± 0.05). Phenotypic correlations of WW and GRTS tended to be low to moderate with other traits (except SW with GRTS with was 0.93 (± 0.01). Genetic correlations tended to be high except with GRTS but these had large standard errors.

Table 3.7 shows a small negative phenotypic correlation between WW and GRWT (-0.10) but a large genetic correlation between these traits (1.00). This infers a large negative correlation between WW and subsequent growth from weaning to turnout. Age and weight of animals at weaning had significant effects on GRWT (P<0.01). Covariates of weaning age with WW and GRWT were -0.0003 (± 0.0001) and 0.0019 (± 0.0003) respectively.

Table 3.7. Heritabilities (on diagonal), Genetic (below diagonal) and Phenotypic (above diagonal) Correlations for Post-Weaning Traits

	WW	TW	SW	GRWT	GRTS
WW	**0.21** (0.04)	0.32 (0.04)	0.40 (0.04)	-0.10 (0.04)	0.02 (0.05)
TW	0.90 (0.28)	**0.10** (0.05)	0.73 (0.03)	0.76 (0.02)	0.06 (0.05)
SW	0.83 (0.27)	1.00 (n.e.)	**0.14** (0.06)	0.70 (0.03)	0.93 (0.01)
GRWT	1.00 (0.04)	0.80 (0.63)	1.00 (n.e.)	**0.08** (0.05)	0.14 (0.05)
GRTS	-.19 (0.51)	0.98 (1.24)	-.19 (0.86)	1.00 (n.e.)	**0.20** (0.06)

n.e. = not estimable; standard errors are in brackets TW = turnout weight, SW = September weight, GRWT = growth rate from weaning to turnout, GRTS = growth rate from turnout to September

3.3.3. Calving Traits

Date of birth and calving record were examined to see which variables affected them (Table 3.8). Age of dam and pre-rut weight significantly affected date of calving (P < 0.01), with older and heavier dams tending to calve earlier.

Table 3.8. Least Squares Means and Deviations for Fixed Effects and Covariables for Hind Traits (standard errors)

	Date Calving	Barren/Fertile	Survived/Died
Dam Age 2	20th June	0.446	0.660
3	-10.80 (1.70)	0.36 (0.03)	-0.05 (0.07)
4	-12.40 (1.67)	0.48 (0.04)	-0.02 (0.07)
5	-12.36 (1.68)	0.48 (0.04)	-0.08 (0.07)
6	-11.52 (1.74)	0.48 (0.04)	-0.11 (0.08)
7	-10.60 (1.73)	0.49 (0.04)	-0.06 (0.08)
8	-14.63 (1.74)	0.48 (0.04)	-0.05 (0.08)
9	-14.36 (1.77)	0.52 (0.04)	-0.10 (0.08)
10	-18.03 (1.87)	0.49 (0.04)	-0.07 (0.08)
11	-23.86 (1.99)	0.51 (0.05)	0.03 (0.09)
12	-20.69 (2.05)	0.51 (0.05)	-0.05 (0.09)
13	-18.85 (2.78)	0.49 (0.05)	0.02 (0.10)
14	-18.42 (2.65)	0.44 (0.06)	0.08 (0.11)
Prop. Wapiti 0	7th June	0.869	0.720
0.25	12.20 (1.65)	-0.13 (0.05)	-0.10 (0.13)
0.50	14.11 (1.73)	-0.31 (0.04)	-0.30 (0.07)
Prev. Cal. Rec.[1] 0	10th June	0.738	0.639
1	0.18 (0.95)	0.13 (0.11)	-0.02 (0.03)
2	0.95 (0.88)	0.09 (0.11)	-0.06 (0.03)
Pre-rut Wt	-0.19 (0.04)		0.01 (0.00)
Birth Wt.	0.75 (0.26)		0.02 (0.01)

[1] Previous calving record: 0 = barren the previous year; 1 = gave birth but calf did not survive to weaning; 2 = calf survived to weaning;

The proportion of Wapiti parentage of the calf and calf birth weight indicate that heavier calves tended to be born tended to be born later ($P < 0.01$), although Wapitis do tend to have a longer gestation period (Fletcher, 1986). With calving record, older animals are more likely to produce a healthy calf ($P < 0.01$) but there is little change after 4 years of age. Age of hind has little influence on whether the calf survives after birth ($P>0.05$). Calves of higher proportion of Wapiti parentage are less likely to survive to weaning ($P<0.01$).

Repeatabilities (r), heritabilities on the normal scale (h^2_n) and general environmental variance ratios (V_{Eg}/V_p) for these traits are given in Table 3.9. This shows that the permanent effect of the dam on date of calving is non-genetic or general environmental (therefore r measures $V_{Eg}/(V_{Eg} + V_{Es})$) while all for calving record is additive genetic.

Table 3.9. Repeatabilities, Heritabilities and General Environmental Variance Ratios for Traits on Hind

	Date of Birth[1]	Barren/Fertile[2]	Survived/Died[3]
r	0.17 (0.02)	0.07 (0.05)	0.05 (0.03)
V_{Eg}/V_p	0.17	0.00	0.00
h^2	0.00	0.07	0.05

[1] s.d. = 11.41; [2] p = 0.144, n = 1698, h^2_b = 0.03; [3] = p = 0.606, n = 1453, h^2_b = 0.03; (h_b^2 is the heritability on the binomial scale and h^2_n is the heritability on the normal scale)

Table 3.10 shows significance levels for fixed effects and covariates on date of calving and calving record. Previous calving record had a significant effect on calving record ($P<0.01$), hinds having calved in the previous year being less likely to produce a healthy calf the following year. This is likely to be due to suckling/newly weaned hinds being in relatively poorer condition at the rut.

Table 3.10. Mean Squares and Significance Levels for Fixed Effects and Covariates on Traits of Hind

	Date of Birth	Barren/Fertile	Survived/Died
Dam Age	2211.80**	3.15**	0.51^{NS}
Prop. Wapiti	7271.51**	2.81**	3.77**
Previous Calving Record	926.01*	0.31*	4.54**
Year	1754.68**	0.52**	7.01**
Residual MS	144.42	0.12	0.24

NS - not significant; * $P < 0.05$; ** $P < 0.01$

3.3.4 Hind Weight

Hinds were weighed at various intervals throughout the year. These weights were examined to see what affected the weight of animals at various stages during the reproductive cycle. A summary of weights is given in Table 3.11 with repeatabilities and correlations given in Table 12a. Means, Coefficients of variation and standard deviations were of the same order for all traits.

Table 3.11. Summary Statistics for Hind Weights

	Mean	σ_p	C.V.	Number
Pre-Rut	81.49	9.49	11.5	1020
December	81.20	8.37	10.2	1020
February	81.76	8.03	9.8	1020
April	79.16	7.86	9.8	1020

Table 3.12a. Repeatabilities (on diagonal), Phenotypic (above diagonal) and Genetic (below diagonal) Correlations for Hind Weights

	Pre-Rut	December	February	April
Pre-Rut	**0.58** (0.02)	0.89 (0.01)	0.76 (0.02)	0.79 (0.02)
December	0.99 (0.01)	**0.67** (0.02)	0.82 (0.01)	0.85 (0.01)
February	0.99 (0.01)	1.00 (0.01)	**0.56** (0.03)	0.80 (0.02)
April	1.00 (0.01)	0.99 (0.01)	0.99 (0.01)	**0.67** (0.02)

Table 3.12b. Heritabilities (h^2) and General Environmental Variance Ratios (V_{Eg}/V_p) for Hind Weights

	Pre-Rut	December	February	April
h^2	0.26	0.34	0.38	0.34
V_{Eg}/V_p	0.32	0.33	0.19	0.33

Hind weight is highly repeatable from year to year and weights of hind at different times of the year are phenotypically highly correlated with each other. Genetic correlations are biased because of the inclusion of environmental variances in the calculation For example, during the winter animals have a diet which contains higher fibre than in the summer months and so this is retained in the gut for longer so increasing the weight of the animal. A measurement of condition of the hind should be included to give a fairer picture of hind weight. The effects of general environment and heritability on these repeatabilities are given in Table 3.12b. Heritabilities are similar for all traits, with pre-rut weight the lowest (0.26) while February weight has the lowest V_{Eg}/V_p (0.19).

3.4 Discussion

This is the first study to estimate genetic and phenotypic parameters for traits measured on farmed deer in the UK. Estimates of fixed effects indicate that which environmental factors are important in the expression of growth and reproduction traits in Red deer, while heritabilities and correlations are necessary to develop breeding programs to improve the economic merit of the species.

Animals born in upland areas are usually sold on to farms elsewhere in the country for post-weaning rearing and fattening (Hamilton, 1986). Weaning weight is used by the hind-calf producer as an indicator of an individual's growth potential, dam's maternal ability and the genetic value of sires (Woodward *et al.*, 1989). Post-weaning heritabilities are low but WW, TW and SW are highly correlated. Selection on WW would therefore be useful in improving growth traits to slaughter as it has a high heritability. This also suggests that selection on any one of these could lead to an increase in liveweight for age and also mature weight of breeding animals. This may affect the economics of the deer enterprise as heavier breeding stock require more feed inputs over their lifetime. The data presented here indicates that FL is not a good indicator of growth after birth.

BW is usually only measured to allow computation of average daily gain to weaning and is not used as a primary selection criteria (Barlow, 1978). The loss of this information is not critical, although if calving difficulty became a problem with farmed deer its measurement may be necessary. The correlation between WW and BW also indicates that if selection is placed on WW a correlated increase on BW may be expected, which has implications for increasing calving difficulty. This would be of particular importance on upland/hill farms where there is little/no selection intensity on hinds and stags of higher mature weights are imported onto these farms to improve growth characteristics of the calves. BW, therefore, needs to be monitored.

Fixed effects for pre-weaning traits reflect the importance of the dam in the performance of calves during this period. Hinds of greater than 4 years of age plateau for BW but WW continues to increase with dam age, possibly indicating that selection of hinds on the basis of calf weight at weaning has taken place. The growth of offspring of immature hinds are likely to limited by hind appetite, body size and consequently milk supply.

Fixed effects for WW and post-weaning growth traits have large standard errors. Post-weaning growth traits are less likely to be affected by hind characteristics. The low heritabilities for post-weaning traits may be a reflection of the small number of animals from hinds with few records for these traits.

Superior growth characteristics of Wapiti cross animals indicate the usefulness of the Wapiti as a terminal sire. For example F_1 Wapiti animals have a higher growth rate to weaning (+0.037kg/day, Table 2) and post-weaning (0.075 and 0.028kg/day in the two post weaning periods). Wapiti cross animals are less likely to survive to weaning, be may be due to a hind/stag dimorphism. Hamilton (unpublished data) shows that leg length of Wapiti animals has an effect on dystocia at birth. Care with selection of hinds with Wapiti stags is therefore essential.

Parameters for calf growth traits estimated here differ markedly from those estimated on New Zealand farms (Rapley, 1990). These New Zealand estimates of heritability may be inflated due to a confounding of sire with group effect to weaning and possible an interaction of sire nested within herd and year. The New Zealand estimates are also based on small numbers of animals over a range of environmental conditions, while these estimates are within a single farm. Comparing estimates calculated here with those for Black face sheep (Atkins, 1986) reared in a similar environment, BW and WW estimates are higher (0.27 and 0.21 respectively versus 0.13 and 0.05 for sheep data) while estimates for post-weaning traits are lower (0.10 and 0.14 for TW and SW versus 0.21 and 0.29). The correlation between BW and WW from Atkins (1986) is also markedly different (-0.07 $\pm$ 0.20) compared with that estimated for Red deer (0.52 $\pm$ 0.10). Correlations between other weights are of similar order for both studies. Atkins (1986) attributes low heritabilities and genetic correlations to the importance of the maternal environment and genotype on a lamb's weight prior to weaning. A review of literature estimates of liveweights in sheep (Martin *et al.*, 1980) concluded that there is considerable variation in the heritability of weaning weight (from zero to about 0.6), heritability estimates being lower when twin lambs eights were considered. Genetic correlations between weights from birth to 16 weeks of age were generally very high, consistently in the range 0.5 to 1.0.

Early calving is desirable for farms in low land areas in the UK, so that hinds can make better use of the earlier grass. Selection of hinds for early calving, on the basis of data presented here, is not likely to bring any useful results, as no genetic variation for calving date was found in this study. This may be a factor of the way animals are managed at the rut, with the introduction of stags stimulating oestrus in the hind (Fisher and Fennessy, 1990) and with the hind conceiving to first or second oestrus (Hamilton and Blaxter, 1980). Blaxter *et al.* (1988) argued that fertility was weight rather than age of dam related. This study shows that dam age, as well as dam weight, is an important source of variation in fertility, at least up to 4 years of age.

Selection of replacement breeding stock on Red deer farms on the basis of improved growth rates is desirable for several reasons. Farmers need their venison animals to be ready for slaughter before a second winter to reduce feeding costs, make the best use of grass and avoid a second winter inappetance period. Potential breeding females need to reach a suitable weight to ensure a healthy pregnancy and calving at 2 years of age. Selection on weight for age or growth rate may lead to an increase in calving difficulty (at present at a very low rate in deer) and increase maternal overheads, as mature hinds become heavier.

Chapter 4. Within-farm Estimates of Genetic and Phenotypic Parameters for Growth and Reproductive Traits

4.1 Introduction

Chapter 3 dealt with the estimation of parameters on a large farm in the North East of Scotland. Since the establishment of the farm at Glensaugh in 1969, deer farming has become a realistic alternative to conventional farming enterprises. The industry has spread south and farms are now being stocked not only with animals from the Highlands of Scotland but also from English Parks and European forests, along with animals of various proportions of Wapiti parentage. In this chapter, the results of parameter estimation for traits measured on 8 of these farms are estimated, along with factors affecting the traits of interest.

4.2 Materials and Methods

4.2.1 Data Collection

Farmers were approached to provide data for analysis. The methods of drawing farmer's attention to this project was done by three methods. These included attending the British Deer Farmer's Association (BDFA) annual conference in 1988 where a poster exhibition was put up describing the project and farmers were invited to discuss their ideas and needs for a recording and genetic analysis. An article was written in *'Deer Farming'* magazine (McManus, 1989) outlining the reasons for carrying out a genetic analysis on records. Farmers were also contacted by letter from a list obtained from the *'Deer Farming'* magazine and other sources. Those farmers that responded to one of these methods of communication (27 in total) were sent a questionnaire asking for details of their farming enterprise, size of farms, number of hinds and stags and mating schedules.

Not all those farmers who responded to the questionnaire kept suitable performance records on their animals. The reasons why the records were unsuitable included insufficient records and lack of 'objective' records. Many farmers are new entrants to deer farming and in some cases new to farming. 'Insufficient records' included the fact that many farmers had only 1 stag, small herds, in many cases the number of years over which data was kept was limited, some farmers used multiple stag mating, and some farmers had no parental information on their calves. Some farmers did not weigh their calves but rather classified them as 'good', 'moderate' etc. These were also deemed not suitable for analysis. Eight of the original farms had suitable records for analysis.

Methods of Data Recording

There is no national recording scheme for red deer. At the time this project was starting proposals had been made and accepted by the BDFA for a 'Pedigree Recording Register' but this was subsequently dropped by the BDFA. The aims of the register are documented in the Hamilton (1987b). The principal objectives are stated as:

"a) to promote and to provide a register for recording the breeding of farmed deer b) to encourage selection and control in the breeding of farmed deer c) to promote the accurate recording of performance parameters in farmed deer d) to provide a data base of performance parameters from which improvements by selective breeding may be measured e) to provide a source of information on the whereabouts and origins of herds of pedigreed deer".

The herd register confused 'pedigree' with 'genetic superiority'. Tagging at birth was also a necessity for farmers to get their animals into the higher grades of the register, and many farmers are opposed to this. Some of those farmers who disagreed with this register were also wary of this project. At this time also both the BDFA and MAFF were introducing separate tagging systems for farmed deer, which also confused many farmers.

The type of records that are kept, and the form in which they are kept is at the discretion of the farmer. For the purposes of this study a recording scheme was drawn up and farmers were supplied with recording sheets and (if necessary) a computer program written in *Lotus 1-2-3*. From the data collected for this study it was apparent that several methods were used to keep records from lists of weights on pieces of paper, home made record cards, BDFA record cards and various forms of computer recording including the use of spreadsheets and data base systems. These computer packages included *Cardbox, Lotus 1-2-3, Delta 5, Quattro, QByte and Symphony*. There were several problems with data retrieval from these packages. In many cases the data was held in 'transfer' files and could only be retrieved one record at a time, in other cases the program erased the data after 12 months. The data could not be put directly onto the mainframe from these packages in most cases. The 'best' storage methods were those which used the spreadsheet software (*Lotus 1-2-3 or Symphony*), as these were easy to transfer onto the mainframe and were in a form suitable for analysis.

4.2.2 Data

Many farmers tended only to record those calves that could be matched up to hinds. Many farmers only recorded ketchum tag numbers not herd numbers and these could change several times over the life time of a deer. In many cases the date of birth of the hind was not known. Data were available from 8 farms which were distributed around the country from Scotland to Wales and the South of England (Figure 4.1). These farms had varying numbers of records and types of stock as well as recording different traits (see Table 4.1a and b). Most of the farms are relatively new entrants into deer farming.

Table 4.1a Number of Records, Sires and Dams from Each Farm Supplying Data

Farm	No. Records	No. Sires	No. Dams
1	568	7	187
2	460	6	213
3	757	17	372
4	97	9	84
5	151	6	108
6	171	4	103
7	132	6	57
8	134	4	69

Figure 4.1 Location of Farms Supplying Data for Chapter 4.

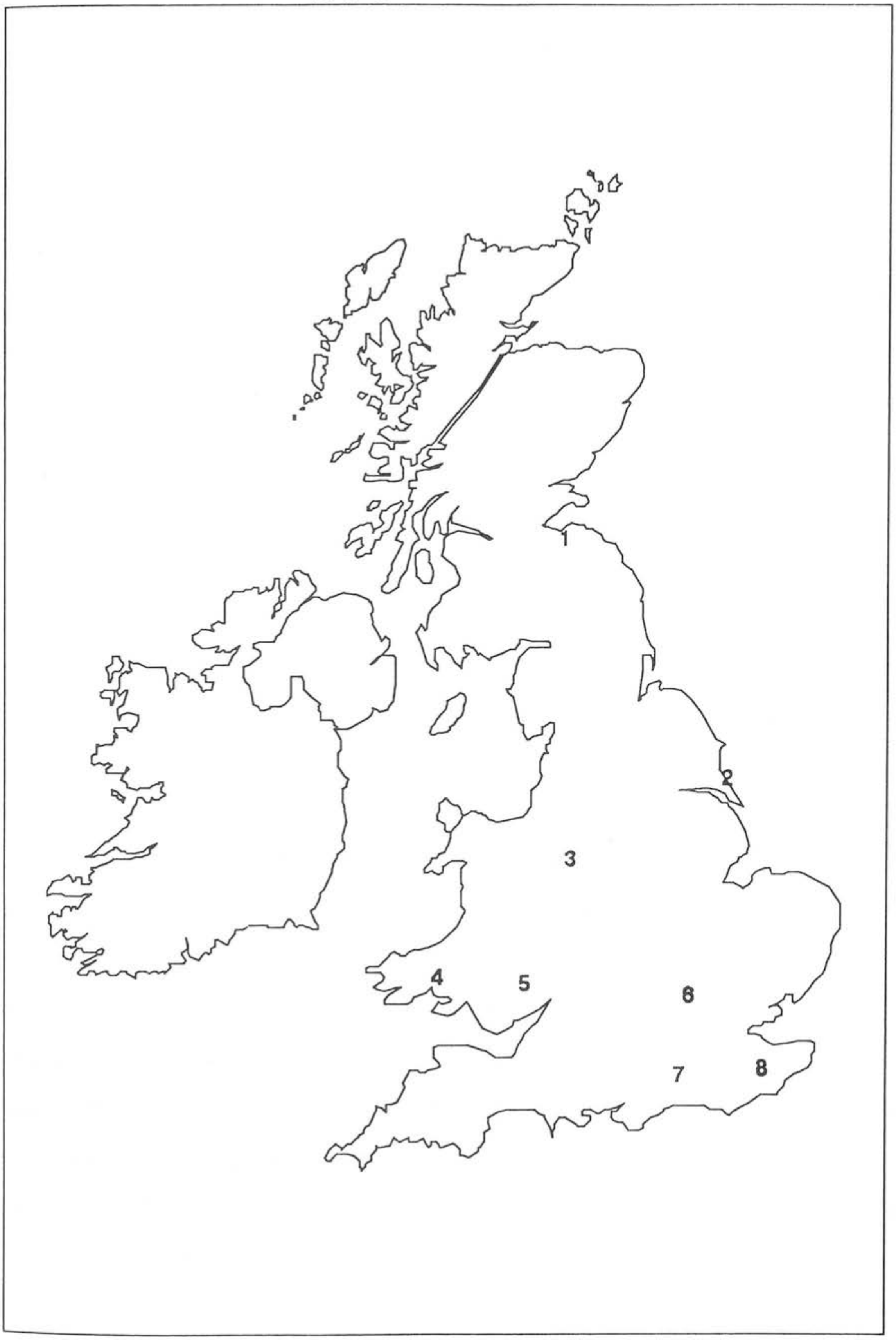


Table 4.1b. Summary of All Data Collected

Farm	DC[1]	BW[2]	WW[3]	MW[4]	TW[5]	OW[6]	Stock[7]
	√	√				Carcass	Scottish
2	√	√	√		√	1yr/2yr/3yr	English
3	√	√	√		√		English
4			√	√	√		European
5	√		√	√			European, English, Scottish
6	√		√	√	√		English
7	√		√	√	√	1yr	Wapiti
8	√		√	√	√		English

[1] DB = Date of Calving; [2] BW = Birth Weight ; [3] WW = Weaning Weight
[4] MW = Mid-winter weight ; [5] TW = Turnout weight ; [6] OW = other weights ; [7] = Origin of breeding stock where Scottish refers to Scottish Hill, English refers to English Park, European refers to European Forests.

4.2.3 Farm Management

Management on the farms sampled was similar in most cases. Single sire rutting (a single stag with a group of hinds during the breeding season) was practised on all farms. Stags were introduced to the hinds in September, the rut generally lasting from September to December. Winter management of the hinds varied depending on the individual farm. Some hinds were outwintered while others were housed and turned out to grass in April. Calves were generally born in May/June and suckled at grass until weaned in mid-September at approximately 100 days of age. Calves were usually housed in October and fed silage/hay and concentrates. Turnout of calves to grass was again in April. Selection for breeding or slaughter took place in September (when calves were approximately 15 months of age). Most farms were increasing their herd numbers during the period studied here and so the majority of females were kept as breeding hinds. The animals for slaughter were usually shot in the field and so little information on carcass traits is available.

4.2.4 Statistical Analysis

Each trait on each farm was analyzed using all the available records. Traits were analyzed to identify the most important effects so that the most appropriate model could be fitted for each trait. Effects included sex of calf, age of hind, year of calf birth and group (which referred to the origin of stock on the farm, i.e. whether the deer were Scottish Hill, English Park or of European or Wapiti parentage). Phenotypic and genetic parameters were estimated using multivariate Restricted Maximum Likelihood (REML) techniques (Meyer, 1985), and fitting an individual animal model (IAM) with all known pedigrees accounted for. All traits were analyzed within farm since no cross farm linkages could be identified. Date of birth was analyzed as a trait of the hind by fitting the dam as an individual in a Derivative Free Restricted Maximum Likelihood (DFREML; Meyer, 1989) analysis. Repeatability, heritability and general environment effects were estimated as in Chapter 3.

4.3 Results

Results are presented as a general summary for all farms is presented and individual farm analyses are given in Appendix II. Traits are divided into pre-weaning, post-weaning and other traits. While no individual farm has data on all traits, it is hoped that useful information can be deciphered from looking at each farm in conjunction with other farms. It is also possible to see if there is any pattern between farms in different areas of the country. In many cases rather than present many tables in the text the reader will be referred to the Appendix II.

4.3.1 Pre-Weaning Traits

Pre-weaning traits include date of calving (DC; days), birth weight (BW; kg) and weaning weight (WW; kg). While 7 farms recorded DC (Farms 1 - 3 and 5 - 8) and WW (Farms 2 - 8) only 3 recorded BW (Farms 1 - 3). Fixed effects included sex of calf, hind age, type of stock (where applicable) and year of birth of calf.

Date of Calving

Table 4.2 gives a summary of the dates of calving for the different farms (DC). The average date of calving ranged from 14 June (Farm 6) to 6 June (Farm 8). There was a slight trend for more northerly farms to calve later. Standard deviations and coefficients of variation are of similar order for all farms.

The effect of sex tended to be non-significant on DC. Year effects tended to be significant on all of the farms. Dam age showed the clearest pattern, with older hinds tending to calve earlier. This pattern was evident in all farms. Animals with Wapiti parentage tended to be born later (Appendix II; Farm 7) than English Park animals, while European animals tended to be born earlier (Appendix II; Farm 6). Wapiti animals do tend to have a longer gestation period than Red deer (Fletcher, 1986).

Table 4.2. Summary of Data on Date of Calving for All Farms

Farm	μ	σ	*cv*	*r*	h^2	V_{Eg}/V_p
1	11 June	12.19	28.76	0.15	0.00	0.15
2	11 June	15.55	36.71	0.19	0.05	0.14
3	8 June	11.42	28.75	0.37	0.14	0.23
5	9 June	16.11	39.76	0.06	0.00	0.06
6	14 June	17.80	39.49	0.25	0.05	0.20
7	6 June	22.41	59.73	0.12	0.00	0.12
8	8 June	12.73	32.96	0.07	0.00	0.07

μ = mean, σ = standard deviation, *cv* = coefficient of variation, *r* = repeatability, h^2 = heritability, V_{Eg}/V_p = ratio of general environment to phenotypic variance

From Table 4.2 it can be seen that while the repeatability of DC varies considerably between farms (0.06 - 0.37), most farm shave a low heritability for this trait (0.00 - 0.14) and low to moderate values for V_{Eg}/V_p (0.06 - 0.23). This is in general agreement with what was found in chapter 3 (r = 0.17; h^2 = 0.00; V_{Eg}/V_p = 0.17). Farm 3 is the exception, which shows a h^2 = 0.14. Looking at the distribution of calving dates an interesting pattern arises. Those farms which had the stag in contact with the hinds before the start of the rut tended to have more hinds calve in the first 19 days (1 oestrus cycle) of the calving season. Almost 90% of all hinds calved within 38 days of the start of calving.

Birth and Weaning Weights

Tables 4.3 and 4.4 summarise the available data from all farms for BW and WW respectively. Heritabilities for BW, from the 3 farms which recorded this trait, are moderate to high (0.31 - 0.49) and are within standard error estimates of each other. Farms 2 and 3 are in a better environment than Farm 1 and are stocked with English Park rather than Scottish Hinds. They tended to have heavier calves at birth but no direct comparison can be made because there are no reliable links between farms. Standard deviations and coefficients of variation are similar for all 3 farms.

Table 4.3. Summary of Birth Weight Data from Farms 1, 2 and 3 (Standard errors are in brackets)

Farm	μ	σ	*cv*	h^2
1	8.32	1.18	14.24	0.46 (0.12)
2	9.29	1.15	15.81	0.49 (0.29)
3	9.38	0.98	10.41	0.31 (0.15)

μ = mean, σ = standard deviation, *cv* = coefficient of variation, *r* = repeatability, h^2 = heritability

Weaning tended to be at approximately 100 days of age. from Table 4.4 it can be seen that there is a large variation in the estimates of heritability for WW between the various farms. For most farms the heritability is moderate to high (0.22 - 0.89). Farm 8 is the exception (h^2 = 0.01). Genetic and phenotypic correlations for pre-weaning traits were available form Farms 2 and 3. Phenotypic correlations were 0.42 (s.e. 0.03) and 0.43 (s.e. 0.06) and genetic correlations were 0.49 (s.e. not estimable) and 0.70 (s.e. 0.22) respectively for Farms 2 and 3.

Table 4. Summary of WW Data from Farms 2 - 8 (Standard errors are in brackets)

Farm	μ	σ	*cv*	Age WW[1]	h^2
2	51.19	6.24	12.18	108	0.22 (0.26)
3	41.57	6.80	16.35	100[2]	0.67 (0.29)
4	42.98	7.08	16.49	-	0.69 (0.14)
5	41.68	9.24	22.18	101	0.89 (0.17)
6	32.21	7.65	23.76	72	0.43 (0.29)
7	41.57	9.47	22.78	77	0.36 (0.25)
8	44.76	6.05	13.53	98	0.01 (0.03)

μ = mean, σ = standard deviation, *cv* = coefficient of variation, *r* = repeatability, h^2 = heritability; [1] = Age at WW in days; [2]Weight at weaning on this farm was converted to 100 day weight by (((WW-BW)/Age WW) *100) + BW

Male calves were heavier at both birth and weaning than female calves. Hind age also showed a consistent trend for both traits, with older hinds tending to have heavier calves at both birth and weaning (see Appendix II). Year of birth of calf also had a significant effect on these traits. Although no pattern was evident, some farms (eg Appendix II; Farm 2) showed an increase in BW over the years. Age at weaning was an important effect on weight at weaning.

Calves with European and Wapiti parentage were heavier than British Red deer (Scottish and Park) at all stages (Appendix II; Farms 6,7). Generally, the higher the proportion of these parental types in the progeny the greater the benefit in terms of weight for age and growth rates (Appendix II; Farms 4,6,7).

4.3.2 Post-Weaning Weights

For those farms which weighed animals post-weaning, weights included a mid-winter (December) weight (MW; kg; Farms 4-8) and turnout (April) weight (TW; kg; Farms 2-4 and 6-8). All weights were in kilograms. Farms 2 and 7 also had information on weights of animals beyond this period (OW; Kg). Tables 4.5, 4.6 and 4.7 summarise the available farm data for these traits.

Table 4.5. Summary of Data on MW for Farms 4 - 8 (Figures in brackets are standard errors)

Farm	μ	σ	cv	Age MW[1]	h^2
4	42.98	7.08	16.49	-	0.42 (0.19)
5	59.57	13.92	23.37	192	0.68 (0.52)
6	46.82	8.67	18.50	169	0.48 (0.29)
7	60.39	10.55	17.46	193	0.33 (0.25)
8	59.18	6.92	11.70	186	0.01 (0.06)

μ = mean, σ = standard deviation, *cv* = coefficient of variation, *r* = repeatability, h^2 = heritability; [1] = Age at MW in days;

Table 4.6. Summary of Data on TW for Farms 2 - 4 and 6 - 8 (Figures in brackets are standard errors)

Farm	μ	σ	*cv*	Age TW[1]	h^2
2	80.08	13.46	16.40	317	0.37 (0.07)
3	67.16	9.92	14.77	314	0.40 (0.27)
4	76.31	14.89	19.52	-	0.42 (0.24)
6	55.40	9.04	16.32	263	0.45 (0.28)
7	70.24	11.00	15.66	322	0.37 (0.25)
8	79.45	11.56	14.55	315	0.08 (0.13)

μ = mean, σ = standard deviation, *cv* = coefficient of variation, *r* = repeatability, h^2 = heritability; [1] = Age at TW in days;

Heritabilities for these post-weaning traits tended to be moderate to high (0.33 - 0.68 for MW and 0.37 - 0.45 for TW).

Farm 8 was again the exception (heritabilities of 0.01 and 0.08 for MW and TW respectively).

Table 4.7. Summary of OW for Farms 2 and 7 (Figures in brackets are standard errors)

Farm	Weight	μ	σ	cv	h^2
2	15 mth	102.86	18.39	17.85	0.71 (0.07)
2	27 mth	105.97	11.04	11.59	0.42 (n.e.)
2	39 mth	113.57	7.45	6.56	0.90 (0.25)
7	15 mth	93.11	18.73	15.87	0.37 (0.25)

μ = mean, σ = standard deviation, *cv* = coefficient of variation, *r* = repeatability, h^2 = heritability

Trends here were similar for those discussed in the previous section on weaning weight and turnout weight. Male calves maintained their weight advantage at all stages. The effect of dam age and age at weighing remained to mid-winter weight but both these effects tended not to be significant at subsequent weighings.

Which type of stock to choose as male and female breeding stock is of interest to farmers from an economic point of view. It will depend on overhead costs for maintaining female stock, calving difficulties and growth rates. From the data on Farms 5 and 7 (Appendix II; Table 22, 31) it can be seen that animals with European and Wapiti parentage have higher liveweights and growth rates than British stock at the same time/period of the year. These data, together with those from Farm 4 (Appendix II, Table 19), show that pure-bred animals have superior growth traits to crossbreds. No information was available to ascertain traits such as calving difficulties with the various types of stocks although farmers report very low levels of calving difficulties with all types of stock.

Genetic and phenotypic correlations between these traits were all calculated within-farm. Table 4.8 shows a summary of the ranges of these correlations. Estimates of phenotypic and genetic correlations were moderate to high. Standard error estimates on phenotypic correlations were generally low (<0.08) but were higher for genetic correlations (0.20 - 0.50) which were more variable. Correlations between closest weighings tended to be the highest.

Table 4.8. Range of Genetic (below diagonal) and Phenotypic (above diagonal) Correlations for Post-Weaning Traits.

	WW	MW	TW	15 mth
MW		0.59-0.88	0.40-0.68	0.33-0.48
MW	0.41-1.00		0.78-0.88	0.71
TW	0.29-1.00	0.74-1.00		0.77-0.88
15 mth	-0.14-1.00	0.70	1.00	

WW = weaning weight, MW = mid winter weight, TW = turnout weight and 15 mth = weight at 15 months of age

4.3.3 Carcass Traits

Only one farm (Farm 1) had information on carcass traits. Records were available on 163 animals which were slaughtered over a 5 year period from Farm 1. The traits recorded included gross dead weight (GDW; kg), dead carcass weight (DCW; kg) and killing-out proportion (KO). Table 4.9 shows a summary of the data. No information was available on other weights of these animals.

Males had significantly higher GDW and DCW than females. Males also had slightly lower KO but this was not significant. Year (of slaughter) had a significant effect on the weights as did age at slaughter, heavier animals generally weighing more.

Table 4.9. Summary of Carcass Traits for Farm 1

Trait	μ	σ	cv
GDW (kg)	87.46	14.20	16.23
DCW (kg)	47.92	8.46	17.65
KO	0.55	0.04	7.55
Age (months)	18.59	5.90	31.72

Table 4.10 gives correlations and heritabilities measured after slaughter on Farm 1. Heritabilities of GDW, DCW and KO were moderate to high (0.26 s.e. 0.19, 0.31 s.e. 0.19 and 0.59 s.e. 0.30 respectively). GDW was very highly phenotypically correlated with DCW (0.89 s.e. 0.02) but lowly with KO (0.03 s.e. 0.08). Genetic correlations tended to be high.

Table 4.10. Heritabilities (on diagonal), Phenotypic (above diagonal) and Genetic (below diagonal) Correlations for Traits Measured at Slaughter on Farm 1 (Figures in brackets are standard errors).

	GDW (kg)	DCW (kg)	KO
GDW	**0.26 (0.19)**	0.89 (0.02)	0.03 (0.08)
DCW	1.00 (0.00)	**0.31 (0.19)**	0.48 (0.06)
KO	1.00 (n.e.)	1.00 (0.00)	**0.59 (0.30)**

GDW = gross dead weight, DCW = dead carcass weight, KO = kill out proportion

Sex, year and age at slaughter all had significant effects on the three traits measured. Males tended to have heavier carcasses and higher KO than females.

4.4 Discussion

The parameters estimated here show a high degree of genetic variation for weight traits measured on red deer on lowland farms. This should result in rapid genetic gain in these traits, if accurate. The heritabilities estimated here are of the same order as those estimated for the New Zealand deer population (Rapley, 1990) but tend to be higher than those summarised by Barlow (1978), and Preston and Willis (1970) for beef cattle. This is likely to be due, in part, to the fact that the farmed deer population has, to date, been subjected to very little selection. Estimates of parameters are also higher than those estimated in Chapter 3 and by Atkins (1986) on sheep in a hill area. This is likely to be due, in part, to better environmental conditions on these farms. It must be remembered that the heritability is a property of a population as well as of a character (Falconer, 1989). This may account for part of the different estimates between farms.

Estimates of heritabilities from Farm 8 are markedly different from those estimated for other farms. The breeding stock for Farm 8 all came from a single park in England. No new introduction of stock had been made into this park for several generations and culling had been on the basis of antler and body size. The genetic base is therefore narrow. While REML procedures used here will estimate the heritability in the base population accounting for inbreeding, it can only do so provided information on the relationships between the animals is included in the pedigree file. Since no information on genetic relationships between the parent stock is available for Farm 8 parameter estimates are based on available information. Inbreeding decreases the genetic variation between the inbred animals (Bulmer, 1971; 1976; Falconer, 1989) and so, as can be seen in this case, estimates of genetic parameters are low.

Phenotypic and genetic correlations estimates are of similar order of those found for New Zealand deer (Rapley, 1990). The range of estimates here reflect the fact that different environmental factors are operating on different farms. Martin *et al.* (1980) in a review of estimates of parameters for sheep liveweights from birth to 4 months of age show a range of genetic correlations (0.5 - 1.0). The highest correlations were between adjacent weights.

The size of genetic correlations between weights at various ages suggests that selection for any one weight would result in a positive change in all weights. Selection on weaning weight has received more emphasis when animals are grown and finished on pasture (Rendel *et al.*, 1968; Clifford and McDonald, 1972) and where a high proportion of costs are incurred in feeding growing animals, most emphasis has been placed on growth after weaning (Barlow, 1978).

Only one farm had information on carcass traits (Farm 1). Heritabilities for traits measured here were approximately 0.3. Sex and year had important effects on carcass traits, as did age at slaughter. Heritability estimates for carcass traits agree with those in other species. Heritability of carcass weight has been estimated for pigs as 0.43 (Cameron, 1990), and 0.31 and 0.33 for 400 day weight in cattle (Mrode and Thompson, 1990; Bishop, 1990 respectively). Kill out was estimated as 0.62 by Renand (1988). Other studies have shown that liveweight at slaughter is the single most reliable measure of total edible portion of the carcass (Berg and Butterfield, 1976).

Environmental factors which affected liveweights traits investigated on the various farms included sex of calf, age of hind and year of birth of calf. For pre-weaning traits age of hind had a significant effect on the trait in question, reflecting the importance of the hind on traits during this period of the life of the calf. The environmental factors considered here have been found to be important in other studies on weights of animals pre-weaning. A significant effect of dam age on birth weight and weaning weight of lambs has been reported by Osman and Bradford (1965) and Shelton and Campbell (1962), and for red deer (McManus and Hamilton, 1991). Male calves had a weight advantage over female calves at all stages, while the effect of year of birth was significant in most cases.

Growth rates or weight for age of deer are important factors in venison production, as in any other meat production system. Many of the new entrants into deer farming setting up farms in areas where there is a longer grass growing season and environmental conditions are better than those encountered in Chapter 3. They have the choice of a range of breeding stock with which to stock their farm. Most farmers tend to choose one type of stock as their dam 'breed' and either the same or another as their sire 'breed'.

Analysis of records here show that animals with Wapiti or European parentage tend to have superior growth rates and weight for age when compared with English or Scottish stock. Although data is limited, it is likely that the use for these 'foreign' types of stock will be as 'terminal sire breeds', in some sort of crossbreeding program. Hinds of European parentage also tended to calve earlier.

Estimates of genetic and phenotypic parameters discussed here are based on relatively small numbers of animals. The estimation of these parameters and the rate of genetic improvement of selected characters would be greatly improved by the use of AI or other techniques to tie the farms together. This would give farmers the ability to identify superior breeding stock from a number of farms and enable superior genetic merit of animals to benefit a number of farmers. With no reliable genetic links between farms there is no method for farmers to compare the performance of their stock with that on other farms. Selection of replacement stock therefore will be on within-farm performance alone. In an attempt to overcome these problems a central performance test was set up, see Chapter 5.

There is a need for a coordinated recording system for deer farmers, and the records kept on a data base by a central agency (BDFA or MAFF). The fact that such a recording scheme is backed by the BDFA or MAFF would encourage farmers to participate. Care must be taken to avoid the mistakes which led to the demise of the pedigree recording scheme (Hamilton, 1987). The scheme was difficult to manage, there being 5 categories of animals, each which had a different coloured tag, males and females being tagged in different ears. This could have led to preferential treatment of those animals which are in the 'higher' categories and which could be easily identified by the colour of the ear tags. Many farmers also felt that it was too difficult for the majority of them to carry out the depth of recording necessary to move from the bottom category.

A centralised recording scheme would mean that future genetic analyses of on-farm records will be from a single data base in a set format and will make both access and analysis of such data simpler than at present. The data base can be updated each year, and farm records built up over a number of years. Farmers can be provided with timely summaries of the performance of their animals and advised on management decisions, which should encourage them to record the performance of their animals.

From a genetic point of view, stags moving from farm to farm can be identified and used to provide across farm links, although the use of this is limited. The setting up of such a data base at this time would be advantageous since there are only a limited number of farmers in deer farming at the present time and many of the farms which new entrants into deer farming are likely to use stock from those farms who would participate in this data collection.

The next chapter looks at different methods of across herd evaluation of deer and gives the result of the first central performance test on Red deer in the UK.

Chapter 5. Central Performance Testing Red Deer

5.1 Introduction

It is unwise to compare animals in different herds without genetic links between them, yet many farmers and breeders make between herd comparisons of stock, ignoring the effect of environmental factors on the level of herd production. Methods of multi-herd animal evaluation procedures have been reviewed by Parnell *et al.*, (1986). The most appropriate methods for establishing genetic linkages across herds were identified as the use of AI reference sires, the participation of farms in co-operative nucleus breeding schemes and the evaluation of potential sires from different farms through central performance testing. The level of AI usage in the deer population is very low at present and so information on genetic relationships between herds is very limited. The setting up of nucleus or group breeding schemes is a complicated process requiring trust and committed input from several farmers to be successful. For these reasons, a central performance test was chosen as the most appropriate method to begin some form of multi-herd evaluation of deer.

Central performance tests (CPTs) are used, in cattle and sheep, to evaluate potential sires, from different farms or environments, for postweaning growth rate under uniform conditions. The aim is to identify those animals which will produce superior offspring (Dalton and Morris, 1978). Frequently, central or on-farm performance tests are used to select sires for artificial insemination (AI) (Foulley *et al.*, 1983). A further objective of the central performance test is to increase selection intensity and so allow greater capacity to select replacement stock (response to selection is affected by selection intensity, variation in a trait and the generation interval). This allows some comparison between contributing herds. High sales potential of high ranking animals makes the test more acceptable (Dalton and Morris, 1978). This chapter presents results and discussion of the first central performance test on red deer in the UK.

5.2 Materials and Methods

This was the first central performance test for deer in the UK. Recommendations for beef cattle performance testing were used as the basis of developing recommendations for this test. This section outlines these recommendations and the reality when applied to centrally testing deer with no infra-structure in place.

5.2.1. Choice of animals to go on test

The selection of animals to go on test should be based on the traits desired in the progeny (Krausslich, 1974). Kemp (1990) advocates a recorded birth date within specified 90-day period (for beef cattle) and a minimum weight per day of age of approximately 1kg at delivery to the test station.

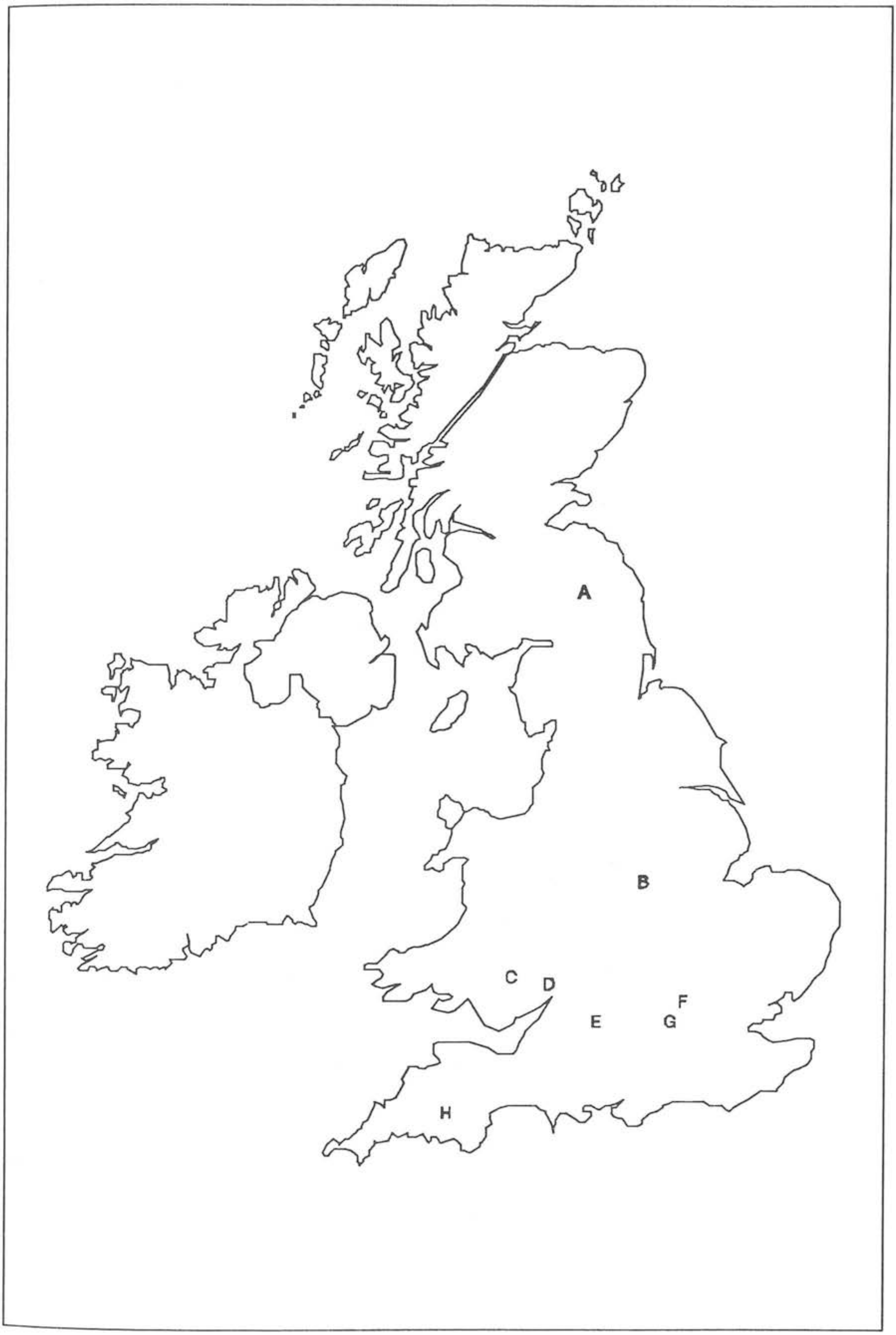
Funding for the test was borne by private individuals. Several farms were approached to contribute animals to the test and these animals were selected by the farmers on individual farms and purchased (unseen) by the farmer running the test. Since there was no previous experience of selecting deer to go on test the resulting deer were a highly variable, in terms of liveweight at the start of test (see later). Deer are seasonal breeders and therefore no limit on the time period in which animals should be born was placed on calves entering the test. Some farmers did not record date of birth. In total 8 farms contributed animals to the test. The location of these farms are shown in Figure 5.1.

5.2.2. Adaption period

This should be sufficiently long enough to allow compensatory growth to equalize the body conditions of the animals. The older the animals the more important this period. This time should be used to eliminate any parasites and equalize vitamin and mineral levels in the animals. The housing should allow easy transfer to the test environment.

The major recommendation is that animals should go on test as soon as possible after they have received colostrum (Bech Andersen *et al.*, 1981) with an upper age limit of 6 weeks (for dairy bulls) or a soon as possible after weaning for beef bulls. A minimum adaption period of 3 weeks is called for but the longer the better.

Figure 5.1 Location of Farms Supplying Animals for Central Performance Test



The deer had to be TB tested before leaving their home farms. TB testing is, as yet, not compulsory for deer farmers. Several farmers had never carried out the test before and so the start of the test was delayed to allow for this. For this reason, deer arrived on the test farm over a three week period from mid October to early November, when the calves were approximately 4 months of age.

5.2.3. Age of animals and length of test period

The test period should be sufficiently long for animals to overcome pre-test effects. Krausslich (1974) discusses various ways to decide when the end of the test should be. Since it is the progeny that are to be improved he suggests that selection should take place when the progeny would normally go to slaughter. For deer this is generally when animals are about 90kg liveweight (A. Darroch, personal communication) although many farmers keep the deer to the end of the first grazing season. In bulls the length of test has been 140 days, with a pre-test adjustment period of 21-28 days (BIF, 1986). After 140 days on test some animals have shown to be overly fat and have unsound feet and legs (Kemp, 1990).

As the bulk of the funding for this test was from a private individual the realisation of some of the invested capital was also a consideration. A minimum test period of 4 months is advised by Bech Andersen *et al.* (1981). Other considerations included the fact that deer have a short breeding season so that any marketing of the selected animals for breeding would have to be in sufficient time for TB testing and marketing to take place. The date for the end of test was decided as turnout (April) and the length of test as 152 days.

5.2.4. Selection for growth rate and correlated responses

There is a correlated response in birth weight when selecting for growth rate. Selection on daily gain will give lower increase in birth weight than selection for yearling weight (Andersen, 1973; Andersen *et al.*, 1974). Selection on relative growth rate also results in reducing the correlated increase in birth weight and mature size (Kemp, 1990) but there is a corresponding decrease in absolute growth rate (Fitzhugh, 1975).

5.2.5. Feeding system

The greater the variability in the environment under which animals are kept the more difficult it is to estimate breeding values of bulls (Krausslich, 1974). Growth rate in young animals is largely a function of appetite, the lean tissue growth capacity and the maintenance efficiency. At a low level of feeding , variation in growth rate is largely affected by maintenance requirement. At a higher level (nearly *ad libitum*), maintenance and lean-tissue growth capacity are the major contributors.

When the bulls enter the station soon after birth then it does not matter whether the bulls are fed according to age or weight. If they enter later, large variation in weight is likely to exist and so feeding according to weight is necessary. A summary of feeding systems is given in Appendix . For the purposes of this test animals were fed concentrates and roughage *ad lib.*, although individual feeding was not possible.

5.2.6. Housing

Individual pens are expensive but allow individual feeding to take place. In loose housing social factors may affect the performance of the bulls, and fighting or riding may occur (Andersen *et al.*, 1981; Krausslich, 1974). Such factors may be important in testing bulls for the situations under which their progeny will be reared. For the purposes of this test animals were loose housed on straw.

5.2.7. Measurements

(a) Liveweight. All weights were measured at the same time of day after the same management routine at the test farm. Liveweight was recorded every four weeks approximately, although a weigh cell broke at the March weighing and took 2 weeks to replace. Weights were taken in kilograms.

(b) Ultrasonic measurements. These were taken on 20 animals at the end of test. Measurements of the *longissimus dorsi* muscle area were taken at the 12th rib, using an Aloka SSD-210 DX

Ultrasonic Real Time Scanner with a 3.5MHz transducer (BCF Technology, Livingston, Scotland). Deer have very course hair and so had to be shaved to bare skin. The deer had to be let wander free in a weighing crate as they could not be measured when held still in a crush. This was due to the deer getting very restless when held in the crush. It was also very difficult to get the transducer head in a suitable position for measurement when the deer was held in the crush.

(c) Body Measurements On 3 occasions (November, February and April) linear body measurements were made on the animals. These linear measurements included height of front and back legs (HFL, HBL respectively), width of shoulders and haunch (WS and WH respectively), girth at front and back (GF and GB respectively) and length of animal (LSH). For a full description of these traits see Chapter 7, this thesis. Feet, temperament and condition score were also recorded in January, February and April. The last 3 traits were measured on a scale of 1 to 5, a description of each point in the scale is given in below. Antler length was also recorded at these times.

Condition Score

This was carried out using guidelines for condition scoring cattle (MAFF, 1984). Body condition scores are estimates of fatty tissue under the skin of certain areas of an animal's body. This method assesses fatness at the tailhead and loin.

Score	Description
1	Poor. No fatty tissue felt between skin and pelvis at tailhead. Over the loin the ends of transverse processes are sharp touch and upper surfaces can be felt easily.
2	Moderate. Some fatty tissue felt under skin at tailhead. On loin, the ends of transverse processes feel rounded. Upper surfaces felt only with pressure.
3	Good. Pelvis can be felt at tailhead. Ends of transverse processes can be felt but a thick layer of tissue is on top.
4	Fat. Pelvis felt only with firm pressure. Transverse processes cannot be felt even with firm pressure.
5	Grossly Fat. Tailhead buried by fatty tissue. No part of pelvis or bone structure can be felt even with firm pressure.

Temperament

Farm animals need to be capable of being handled without any risk of injuring the animal itself, the farmer or damaging the equipment (eg for weighing, administration of anthelminthics etc). Animals were scored on a scale of 1 (best) to 5 (worst) 3 times over the period of the test.

Score	Description
1	Very calm. No signs of nervousness, very easily handled, stands steady when touched. Walks calmly out of handling pen.
2	Calm. Slightly restless, lowers body when touched.
3	Nervous. Tries to avoid being handled, shies away from humans.
4	Excitable. Very nervous, tries to avoid being handled, runs out of handling pen.
5	Very excitable. Rears on hind legs, grinds teeth, tries to butt handler, jumps or rushes out of handling pen. Aggressive.

Feet

With any breeding animal it is necessary that they have sound feet and legs to enable them to withstand the pressures of the breeding season over a number of years.

Score	Description
1	Excellent. Animal stands up well on its toes. Toe nails short.
2	Good. Animal stands well, although not as well on its toes as in 1. Toe nails short.
3	Fair. Tendency to be 'flat footed', toe nails slightly over grown.
4	Poor. Flat feet, over grown toe tails starting to turn up at the end.
5	Very poor. Very flat feet, very long, curled toe nails.

5.2.8. Animals

A total of 83 animals from 8 farms around the country were brought to a single farm in North East England (see Figure 5.1), approximately one month after the calves were weaned. Animals were gradually introduced to weaner pellet and then to full ration. The full ration consisted of ad lib pellet and silage and bedded on barley straw.

Chapter 8 contains further analyses on the linear measurements and weight discussed in this chapter.

5.2.9. Statistical Analysis

Traits were analyzed using REML techniques as discussed in earlier chapters. The general model fitted included farm of origin (8), group (pure English, English x Scottish, Swedish x English, E. European x English, English x English/Scottish and pure Scottish) and, in the case of measurements other than weight, weight on date of measurement was fitted as a covariate.

5.3 Results from Central Performance Test

Table 5.1. shows a summary of the traits (means, standard deviations and coefficients of variation (*cv*) measured over time on the animals on central test.

Table 5.1. Summary of Results from CPT

Traits	μ	σ	*cv*
Wt_8_November	57.57	7.66	13.30
Wt_19_November	58.54	7.77	13.29
Wt_21_January	69.45	7.97	11.48
Wt_15_February	72.94	8.48	11.64
Wt_9_April	86.47	10.06	11.64
Length_November	77.84	4.79	6.16
Length_February	84.89	5.98	7.04
Length_April	88.65	5.56	6.27
Height Front_November	87.77	4.46	4.46
Height Front_February	95.50	3.73	3.91
Height Front_April	99.37	4.34	4.37
Height Back_November	90.02	4.75	5.27
Height Back_February	96.53	3.94	4.09
Height Back_April	101.35	3.89	3.84
Heart Girth_November	97.59	6.56	6.72
Heart Girth_February	105.07	5.15	4.91
Heart Girth_April	108.04	5.03	4.65
Girth Back_November	101.75	7.20	7.08
Girth Back_February	106.66	6.69	6.28
Girth Back_April	107.71	6.17	5.74
Width Shoulder_November	10.49	1.48	14.11
Width Shoulder_February	11.28	1.54	13.69
Width Shoulder_April	13.55	1.26	9.32
Width Haunch_November	14.81	1.64	11.05
Width Haunch_February	17.01	1.62	9.53
Width Haunch_April	19.64	1.78	9.04
Feet_January	2.43	0.87	35.84
Feet_February	2.40	1.05	43.97
Feet_April	2.14	0.79	37.05
Antler Length_January	2.46	3.56	144.05
Antler Length_February	6.50	8.53	131.52
Antler Length_April	24.87	17.40	69.95
Temperament_January	2.18	0.90	41.23
Temperament_February	2.80	0.94	33.56
Temperament_April	2.77	0.88	31.79
Condition_January	2.88	0.72	25.09
Condition_February	2.60	0.34	13.67
Condition_April	2.54	0.31	12.23

weights are measured in kg; linear body measurements and antlers are measured in cm; Feet, temperament and condition have no units)

(Abbreviations used in the text include : _N for a trait measured on 19th November, _J measured on 21 January, _F measured on 15th February and _A measured on 9th April). From Table 5.1 it can be seen that objective traits (weights, body measurements) tend to have lower coefficients of variation than subjective traits (excluding antler development which has the highest c.v.). Widths tended to have higher *cvs* than other body measurements.

5.3.1 Weight Traits

The weight traits examined included weight at start of test (SW), weight at end of test (EW), growth rate on test (GRWT), growth rate from start of test to January (78 days) (GRNJ), growth rate from January to end of test (74 days) (GRJA), weight gained on test relative to start weight (RGRS) and weight gained on test relative to final weight (RGRE). A summary of these traits is given in Table 5.2.

Table 5.2. Summary of Weight Traits on CPT Animals

	X	s	*cv*
Start Weight	57.57	7.66	13.30
End Weight	86.47	10.06	11.64
Growth Rate on Test	0.190	0.042	22.18
Growth Rate Jan-April	0.218	0.060	27.64
Growth Rate Nov-Jan	0.160	0.054	33.50
Rel Growth Rate (End)	0.333	0.058	17.65
Rel Growth Rate (Start)	0.511	0.130	25.51

Weight traits tended to have lower coefficients of variation than growth rates. Growth rates tended to be higher in the second half of the test than the first half but GRNJ had a higher coefficient of variation.

Table 5.3 summarises heritability estimates and genetic and phenotypic correlations for weight traits for animals on CPT. Weight traits tended to have highest heritabilities and growth rates the lowest. Standard errors are low on these estimates. These results may be due to the fact that animals on test were selected on weight before entering the test, also there are only a small number of animals on this test and so any estimates of genetic or phenotypic parameters are affected by sampling biasses. Phenotypic correlations between traits tend to be high, except for growth rates with start weight. Genetic correlations tend to be difficult to estimate, due to the small number of animals on test.

Table 5.3. Heritabilities (on diagonal), Phenotypic (above diagonal) and Genetic (below diagonal) Correlations for Weight Traits Measured on Animals on Central Performance Test (Standard errors are in brackets)

	SW[1]	EW	GRWT	GRJA	GRNJ	RGRE	RGRS
SW	**0.84**	0.61	0.05	0.21	-0.20	-0.34	-0.36
	(0.43)	(0.08)	(0.09)	(0.09)	(0.10)	(0.11)	(0.12)
EW	1.00	**0.77**	0.81	0.72	0.43	0.52	0.50
	(n.e.)	**(0.44)**	(0.00)	(0.04)	(0.09)	(0.09)	(0.10)
GRWT	1.00	1.00	**0.19**	0.77	0.68	0.93	0.92
	(n.e.)	(0.00)	**(0.54)**	(0.05)	(0.02)	(0.01)	(0.02)
GRJA	1.00	1.00	-1.00	**0.30**	0.05	0.65	0.64
	(n.e.)	(n.e.)	(n.e.)	**(0.65)**	(0.10)	(0.07)	(0.07)
GRNJ	-0.12	0.43	1.00	-1.00	**0.77**	0.70	0.69
	(0.39)	(0.09)	(n.e.)	(n.e.)	**(0.64)**	(0.07)	(0.07)
RGRE	-0.97	-0.99	-0.99	-0.99	0.77	**0.05**	0.99
	(n.e.)	(n.e.)	(n.e.)	(n.e.)	(n.e.)	**(0.66)**	(0.00)
RGRS	-1.00	-1.00	-1.00	-1.00	0.88	1.00	**0.04**
	(n.e.)	(n.e.)	(n.e.)	(n.e.)	(n.e.)	(n.e.)	**(0.68)**

1 SW = start weight, EW = end weight, GRWT = growth rate over whole test, GRJA = growth rate January to April, GRNJ = growth rate November to January, RGRE = growth rate relative to weight at end of test, RGRS = growth rate relative to weight at start of test

Table 5.4 gives least squares means and deviations for factors affecting weight at start of test (SW). Group, dam age and herd of origin all had significant effects on weight at start of test. Younger dams tended to have lighter calves at the start of test. There were large differences between farms for weight at start of test. Calves from Farm 2, 3 and 5 were significantly heavier and calves from Farm 6, 7 and 8 significantly lighter compared with those from Farm 1. Calves of pure Scottish, Eastern European x English tended to be lighter than pure English animals.

Table 5.4. Least Squares Means and Deviations for Effects on Weight at Start of Test (SW) (Standard errors are in brackets)

		Start Weight (kg)
Grp	1	57.20
	2	1.44 (0.79)
	3	4.88 (1.44)
	4	-6.77 (1.40)
	5	-4.49 (2.00)
	6	-15.76 (2.14)
DAge	2	54.43
	3	4.73 (1.60)
	4	5.87 (1.89)
	5+	8.87 (1.34)
Farm	1	59.15
	2	10.49 (1.34)
	3	4.20 (1.73)
	4	-3.39 (1.04)
	5	5.76 (1.84)
	6	-11.43 (1.38)
	7	-8.15 (1.63)
	8	-10.67 (1.29)

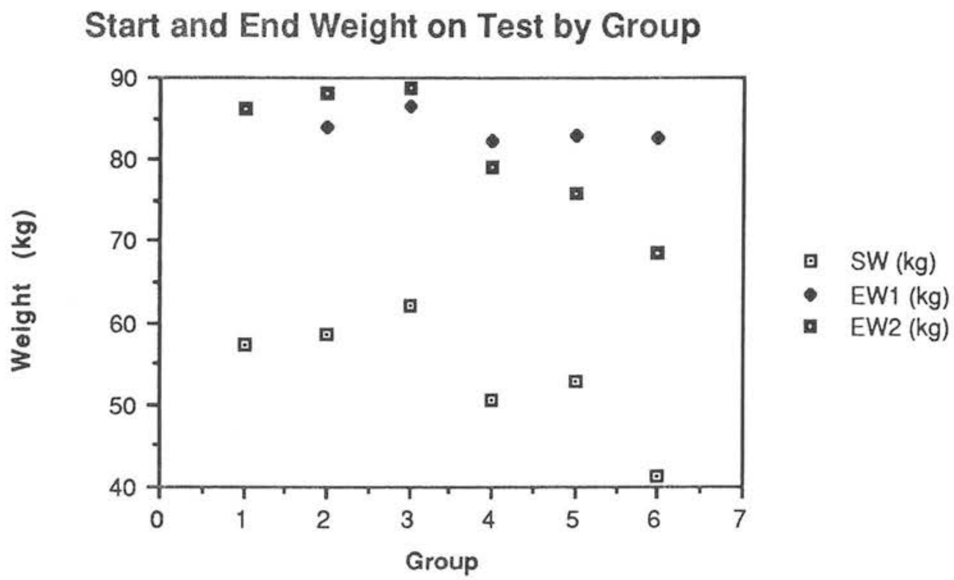
The remaining weight traits were analyzed including (1) and omitting (2) weight at start of test in the model. Tables 5.5 to 5.10 give the results of the analyses of these traits. They are also shown graphically on Figures 5.2, 5.3 and 5.4. Farm of origin tends to be a significant source of variation for weight traits ($P < 0.01$) but not growth rates, when weight at start of test is not fitted in the model. The effect of farm is higher at the end of test than at the start of test. This significance for farm tends to disappear when weight at start of test is fitted. Group tends not to be a significant source of variation ($P > 0.01$).

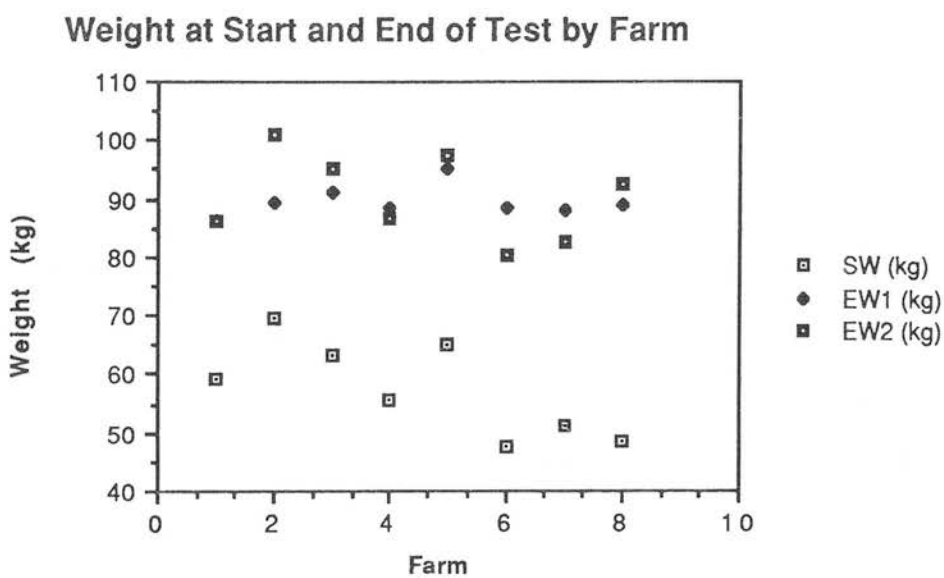
Table 5.5. Least Squares Means and Deviations for Effects on Weight at End of Test Including (EW1) and Not Including Weight at Start of Test (EW2) as a Covariate (Standard errors are in brackets)

		EW1 (kg)	EW2 (kg)
Grp	1	86.13	
	2	-2.35 (2.58)	1.89 (3.23)
	3	0.24 (4.42)	2.44 (5.51)
	4	-3.67 (4.47)	-6.99 (5.56)
	5	-3.07 (6.77)	-10.09 (8.36)
	6	-3.36 (7.39)	-17.52 (8.81)
Farm	1	86.23	
	2	3.29 (3.49)	14.63 (3.77)
	3	5.12 (5.16)	8.89 (6.42)
	4	2.44 (2.74)	0.29 (3.40)
	5	9.03 (5.04)	11.36 (6.29)
	6	2.34 (3.92)	-5.87 (4.64)
	7	1.64 (4.41)	-3.56 (5.42)
	8	2.75 (3.02)	-6.09 (3.35)
Weight		1.01 (0.15)	

When weight at the start of test was included as a covariate in the model neither farm nor group tended to be a significant source of variation in weight at end of test (Figure 5.2). When weight is not included weight at start and weight at end of test follow the same pattern over farms and groups. The regression of weight at start of test on weight at end of test was 1.01 $kg.kg^{-1}$ (s.e. 0.15). Calves from Farm 5 had significantly higher

Figure 5.2 Graph of Group and Farm Least Squares Means for Weight at Start (SW) and End of Test, where Model Includes (EW1) and Excludes (EW2) Regression on Weight at Start of Test.





weight at end of test even after weight at start was included. Weight at start of test did not have a significant effect on growth rate over the whole test period (GRWT) (Table 5.6, Figure 5.3) and again animals from Farm 5 showed significantly higher growth rates.

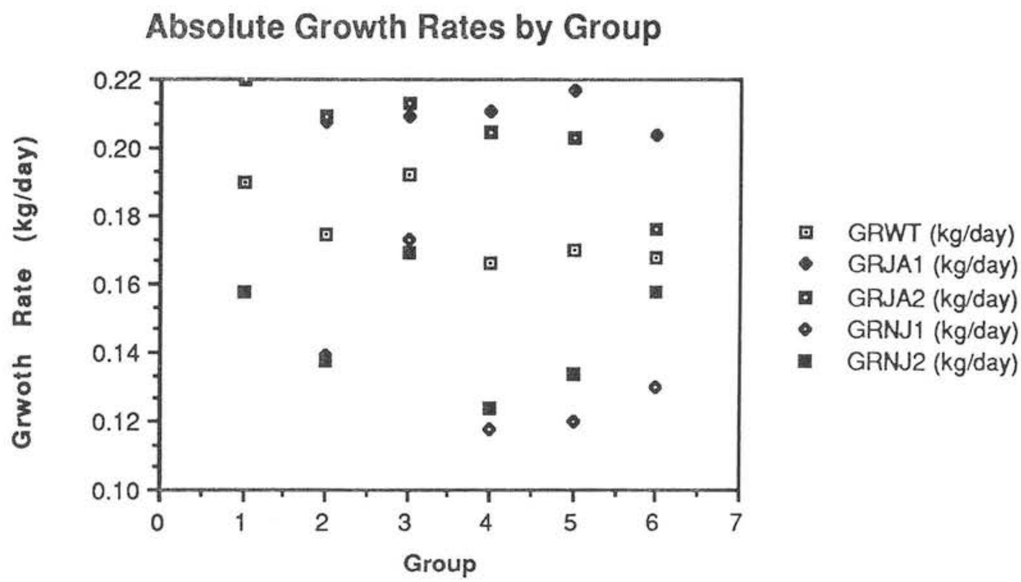
Table 5.6. Least Squares Means and Deviations for Effects on Growth Rate During Test Period Including (GRWT1) Weight at Start of Test as a Covariate (Standard errors are in brackets)

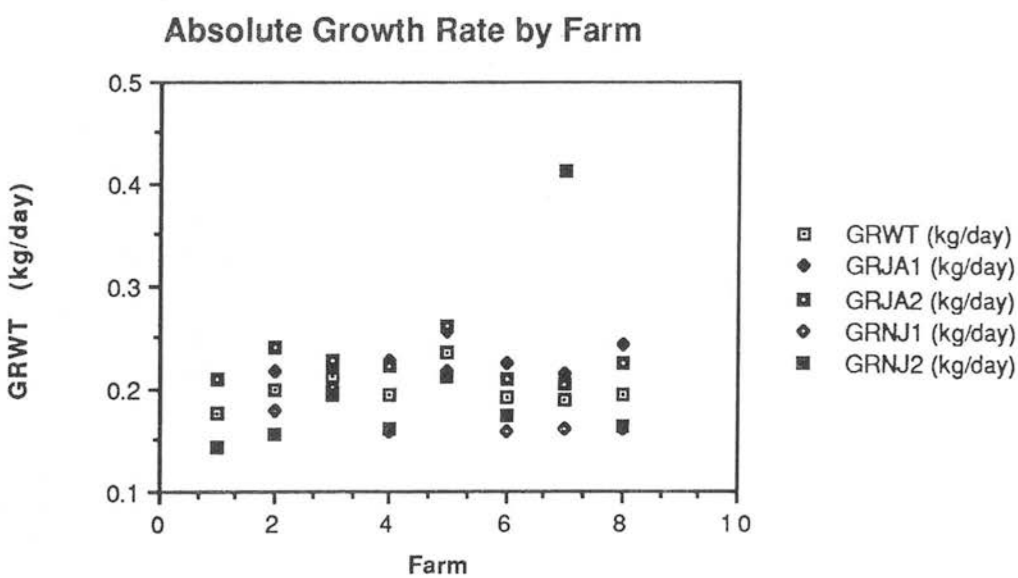
		GRWT1 (kg/day)
Grp	1	0.190
	2	-0.015 (0.017)
	3	0.002 (0.029)
	4	-0.024 (0.029)
	5	-0.020 (0.045)
	6	-0.022 (0.048)
Farm	1	0.178
	2	0.022 (0.023)
	3	0.034 (0.034)
	4	0.016 (0.018)
	5	0.059 (0.033)
	6	0.015 (0.026)
	7	0.011 (0.029)
	8	0.018 (0.019)
Weight		0.000 (0.001)

(Deviations are same when weight was not included and so this is not included in the table)

Tables 5.7 and 5.8 show least squares means and deviations for growth rates in the first 78 days and the final 74 days of the test (Figure 5.3). The regression of start weight on growth rate from November to January was small but negative (possibly indicating some form of compensatory growth for lighter animals going on during this period). The effect of start weight on growth rate from January to April was positive and of the same order as its effect on growth rates from November to January. Animals from Farm 5 again showed the highest effect for these

Figure 5.3 Graph of Group and Farm Least Squares Means for Absolute Growth Rates from Weaning to Turnout (GRWT), January to April (GRJA) and November to January (GRNJ), Including (1) and Excluding (2) Weight at Start of Test as a Regression





traits.

Table 5.7. Least Squares Means and Deviations for Effects on Growth Rate From January to April Including (GRJA1) and Not Including (GRJA2) Weight at Start of Test as a Covariate (Standard errors are in brackets)

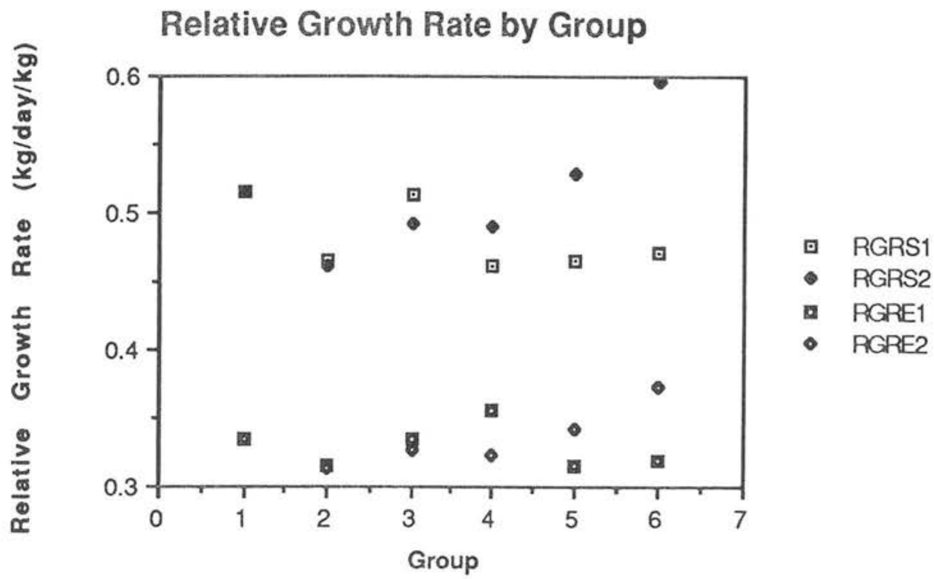
		GRJA1 (kg/day)		GRJA2 (kg/day)	
Grp	1	0.220			
	2	-0.012	(0.024)	-0.011	(0.024)
	3	-0.011	(0.041)	-0.007	(0.041)
	4	-0.009	(0.041)	-0.015	(0.042)
	5	-0.003	(0.063)	-0.017	(0.063)
	6	-0.016	(0.069)	-0.044	(0.066)
Farm	1	0.210			
	2	0.009	(0.033)	0.031	(0.028)
	3	0.010	(0.048)	0.017	(0.048)
	4	0.018	(0.026)	0.014	(0.026)
	5	0.046	(0.047)	0.051	(0.047)
	6	0.016	(0.037)	0.000	(0.035)
	7	0.005	(0.041)	-0.005	(0.041)
	8	0.033	(0.028)	0.016	(0.025)
Weight		0.002	(0.001)		

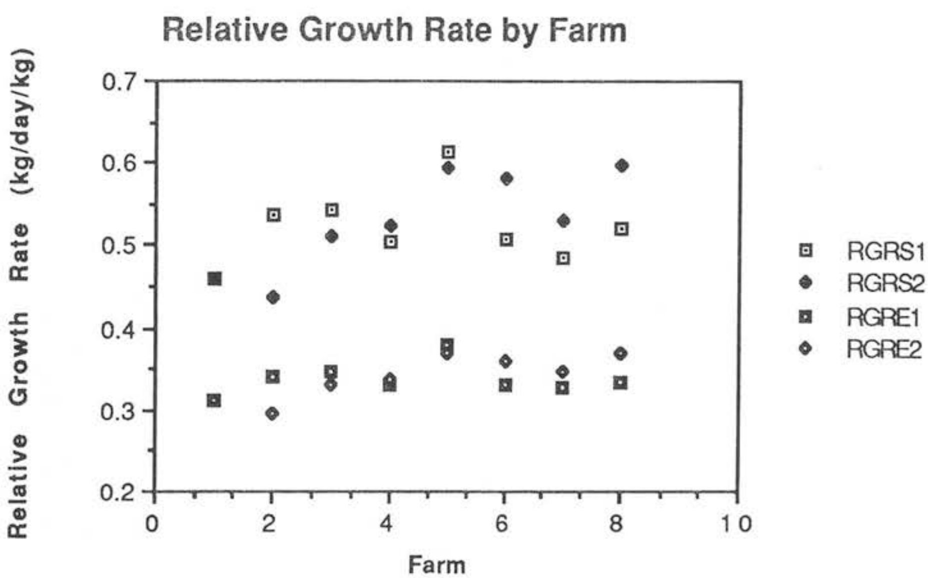
Table 5.8. Least Squares Means and Deviations for Effects on Growth Rate From November to January Including (GRNJ1) and Not Including (GRNJ2) Weight at Start of Test as a Covariate (Standard errors are in brackets)

		GRNJ1 (kg/day)		GRNJ2 (kg/day)	
Grp	1	0.158			
	2	-0.019	(0.021)	-0.020	(0.021)
	3	0.015	(0.036)	0.011	(0.036)
	4	-0.040	(0.037)	-0.034	(0.037)
	5	-0.038	(0.056)	-0.024	(0.055)
	6	-0.028	(0.061)	0.000	(0.058)
Farm	1	0.144			
	2	0.035	(0.029)	0.013	(0.025)
	3	0.059	(0.042)	0.052	(0.042)
	4	0.014	(0.023)	0.018	(0.023)
	5	0.074	(0.041)	0.069	(0.042)
	6	0.015	(0.041)	0.031	(0.031)
	7	0.017	(0.036)	0.027	(0.036)
	8	0.017	(0.025)	0.020	(0.022)
Weight		-0.002	(0.001)		

Relative growth rates (RGR) were calculated relative to weight

Figure 5.4 Graph of Group and Farm Least Squares Means for Growth Rates Relative to Weight at Start (RGRS) and Weight at End (RGRE) of Test, Including (1) and Excluding (2) Weight at Start of Test as a Regression





at start (RGRS) and end (RGRE) of test (as weight gain on test over weight at start and weight at end of test respectively). RGRs tended to be better for lighter animals (Tables 5.9 and 5.10; Figure 5.4). Animals from Farms 5 and 8 had significantly higher RGRs.

Table 5.9. Least Squares Means and Deviations for Effects on Weight Gained over Test Relative to Weight at Start of Test Including (RGRS1) and Not Including (RGRS2) Weight at Start of Test as a Covariate (Standard errors are in brackets)

		RGRS1		RGRS2	
Grp	1	0.516			
	2	-0.051	(0.045)	-0.055	(0.048)
	3	-0.003	(0.077)	-0.023	(0.082)
	4	-0.055	(0.078)	-0.026	(0.083)
	5	-0.051	(0.118)	0.012	(0.124)
	6	-0.045	(0.128)	0.081	(0.130)
Farm	1	0.460			
	2	0.078	(0.061)	-0.023	(0.056)
	3	0.084	(0.090)	0.051	(0.095)
	4	0.044	(0.047)	0.063	(0.050)
	5	0.153	(0.088)	0.133	(0.093)
	6	0.047	(0.069)	0.120	(0.069)
	7	0.025	(0.076)	0.071	(0.081)
	8	0.059	(0.053)	0.138	(0.049)
Weight		-0.009	(0.003)		

Table 5.10. Least Squares Means and Deviations for Effects on Weight Gained over Test Relative to Weight at End of Test Including (RGRE1) and Not Including (RGRE2) Weight at Start of Test as a Covariate (Standard errors are in brackets)

		RGRE1		RGRE2	
Grp	1	0.334			
	2	-0.019	(0.021)	-0.021	(0.022)
	3	0.001	(0.035)	-0.008	(0.037)
	4	-0.022	(0.036)	-0.010	(0.037)
	5	-0.019	(0.054)	0.008	(0.056)
	6	-0.015	(0.059)	0.039	(0.059)
Farm	1	0.311			
	2	0.029	(0.028)	-0.014	(0.025)
	3	0.035	(0.041)	0.021	(0.043)
	4	0.019	(0.022)	0.027	(0.023)
	5	0.067	(0.040)	0.058	(0.042)
	6	0.019	(0.031)	0.050	(0.031)
	7	0.016	(0.035)	0.036	(0.037)
	8	0.025	(0.024)	0.058	(0.023)
Weight		-0.004	(0.001)		

Bullying

Animals were also recorded as to whether they were bullied or not over the period of the test. Bullied animals were scored on a scale of 1 to 4 (1 = no bullying, 2 = slight bullying, 3 = moderate bullying, 4 = severe bullying). In total 18 animals were ascertained to having been bullied. This occurred mainly during the mid winter period and no animals were deemed to having been bullied at the final weighing. The results are given in Table 5.11. Bullied animals tended not to be significantly lighter at the start of test, but did tend to be lighter at the end of test. Slight bullying tended not to have a significant effect on weight or growth traits. The bullying mainly affected GRJA and resulted in significant decreases in growth rates during this period. The effect of severe bullying was somewhat less than that of moderate bullying over the whole test period. This may be because those animals which were subjected to severe bullying were bullied for a relatively shorter time than those subjected to moderate bullying.

Table 5.11. The Effect of Bullying on Weights and Growth Rates of Animals on Central Performance Test (Standard Errors are in Brackets)

		SW[1]	EW	GRWT
Bullying	1	59.12	88.31	0.192
	2	-2.11 (2.04)	-0.10 (3.34)	0.013 (0.017)
	3	0.02 (2.85)	-8.00 (4.65)	-0.053 (0.023)
	4	-1.79 (2.87)	-4.63 (4.68)	-0.019 (0.024)

		GRNJ	GRJA
Bullying	1	0.159	0.223
	2	0.002 (0.022)	0.013 (0.022)
	3	-0.043 (0.030)	-0.063 (0.033)
	4	0.045 (0.030)	-0.076 (0.033)

1 SW = start weight, EW = end weight, GRWT = growth rate over whole test, GRNJ = growth rate November to January, GRJA = growth rate January to April; weight are measured in kg and growth rates in kg/day

5.3.2 Body Measurements

Linear body measurements were made on the animals at 3 stages during the CPT (November, February and April). Animals increased in all dimensions over the period of the test. Weight of the animal on day of measurement tended to be the major significant source of variation ($P < 0.001$) for all the measurements taken and so was fitted as a covariate in all analyses. The effect of weight tended to decrease over time (Table 5.12).

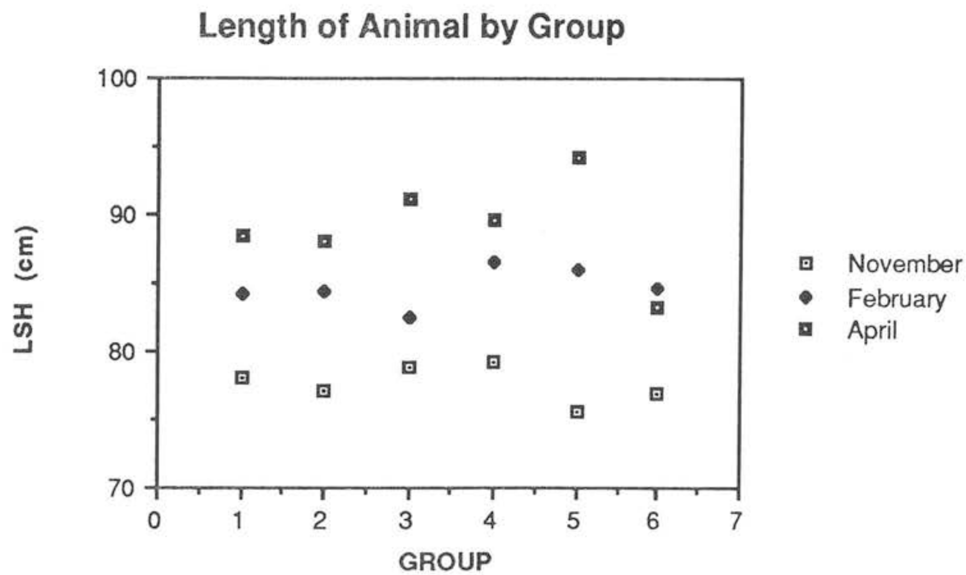
Table 5.12. Effect of Weight on Linear Body Measures

	November	February	April
LSH[1]	0.42 (0.09)	0.40 (0.09)	0.32 (0.05)
HFL	0.40 (0.08)	0.27 (0.05)	0.26 (0.04)
HBL	0.27 (0.10)	0.32 (0.05)	0.27 (0.03)
GF	0.73 (0.10)	0.45 (0.05)	0.39 (0.04)
GB	0.69 (0.12)	0.47 (0.09)	0.42 (0.07)
WH	0.05 (0.03)	0.04 (0.03)	0.06 (0.01)
WS	0.08 (0.03)	0.07 (0.03)	0.03 (0.05)

1 LSH = Length from shoulder to haunch, HFL = height at front leg, HBL = height at back leg, GF = heart girth, GB = back girth, WH = width of shoulder and WS = width of shoulders; all measurements are in cm

Figures 5.5 to 5.11 show the effects of farm and group on these linear body measurements, after fitting weight as a covariate. The results are tabulated in Appendix III. Any differences between the various farms or groups for these measurements could be interpreted as either a result of selection decisions by farmers (such selections were made on basis of visual appraisals of the animals in question or their parents) or differences in form or 'shape' between the animals from different sources. The shape of animals on test is discussed further in Chapter 8.

Figure 5.5 Graph of Group and Farm Least Squares Means for Length of Animal from Shoulder to Haunch (LSH), Measured in November, February and April.



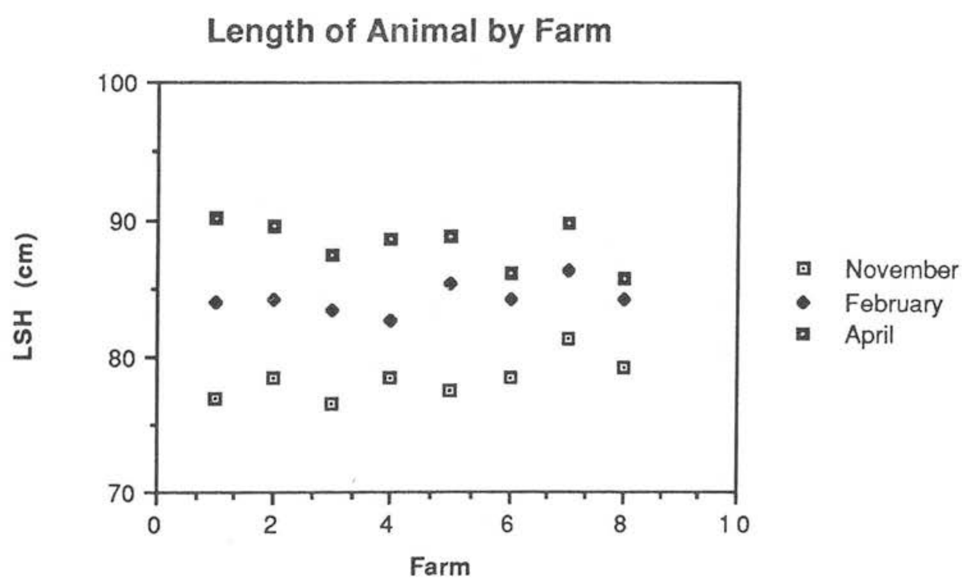
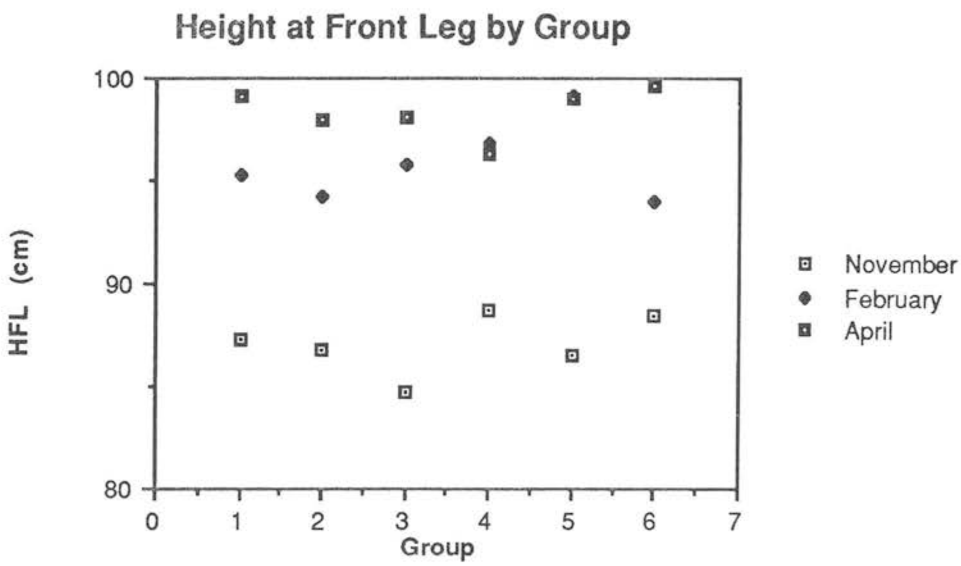


Figure 5.6 Graph of Group and Farm Least Squares Means for Height of Animal at the Front Leg (HFL), Measured in November, February and April.



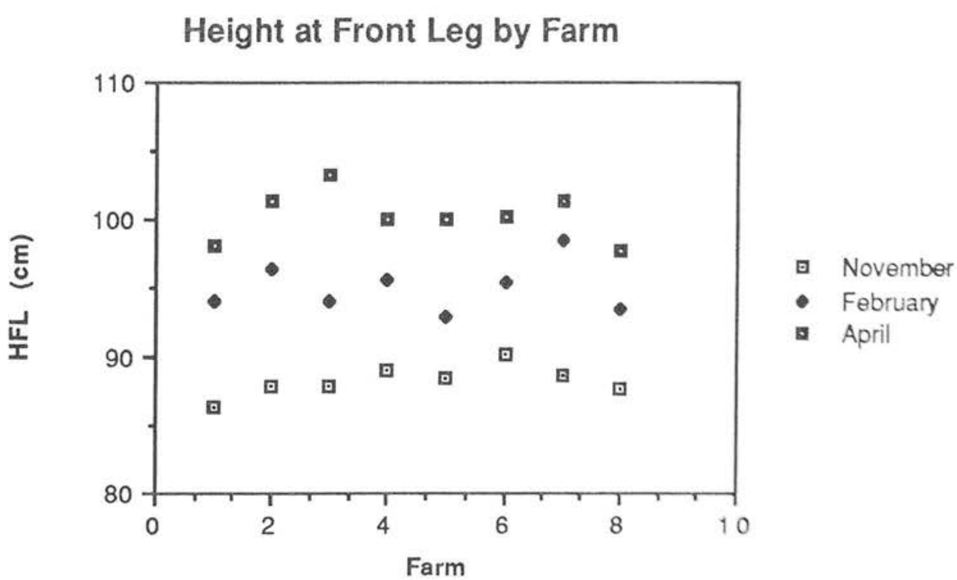
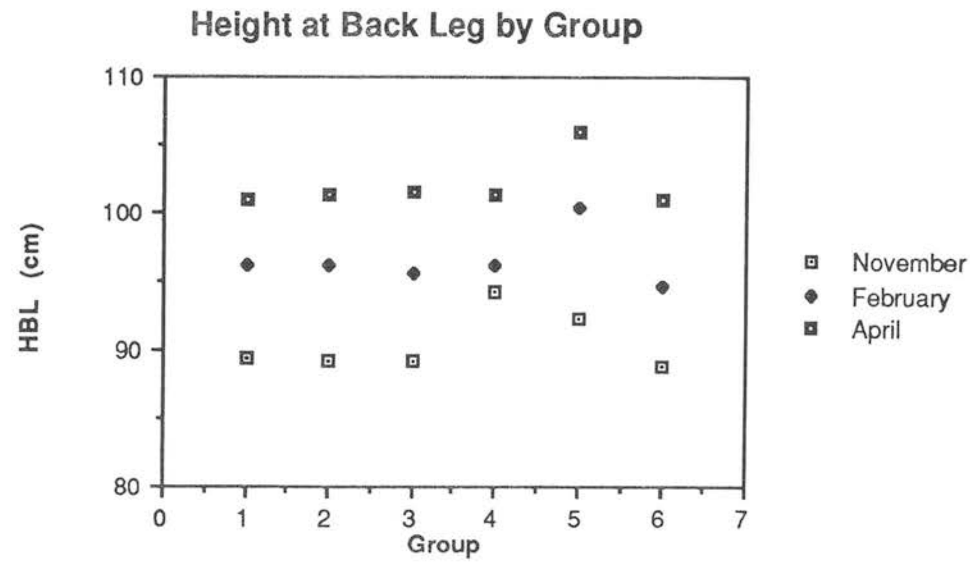


Figure 5.7 Graph of Group and Farm Least Squares Means for Height of Animal at the Back Leg (HBL), Measured in November, February and April.



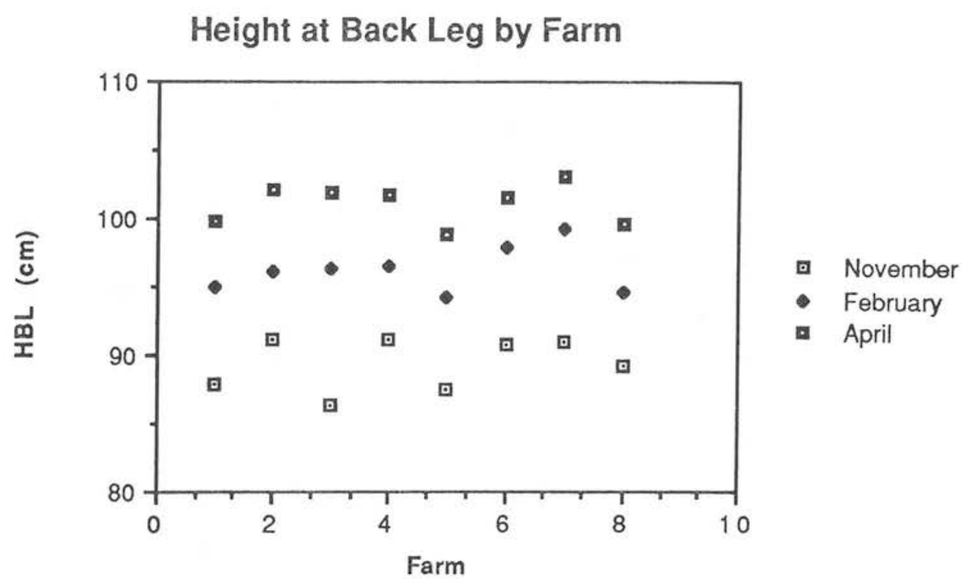


Figure 5.8 Graph of Group and Farm Least Squares Means for Girth of Animal at the Front (Heart Girth; GF), Measured in November, February and April.

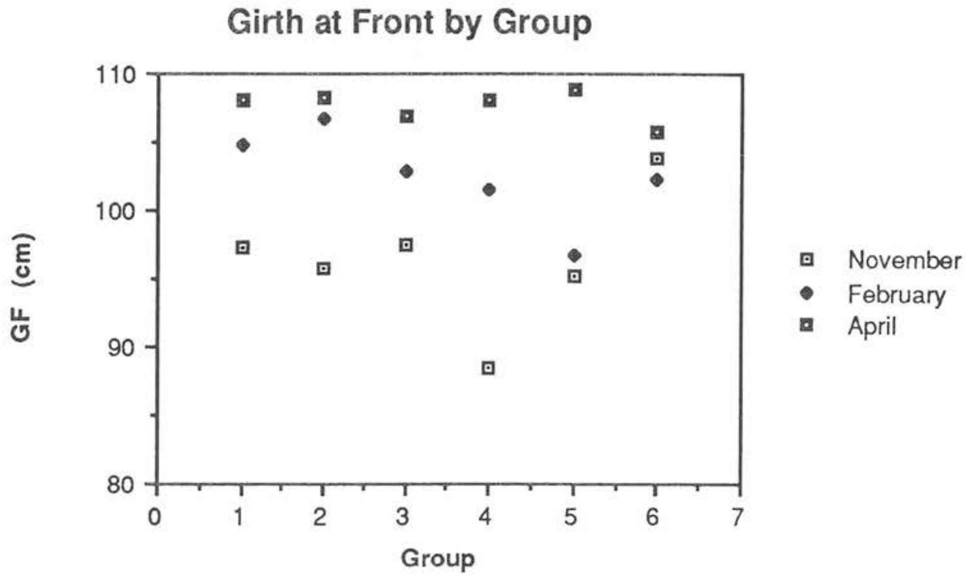
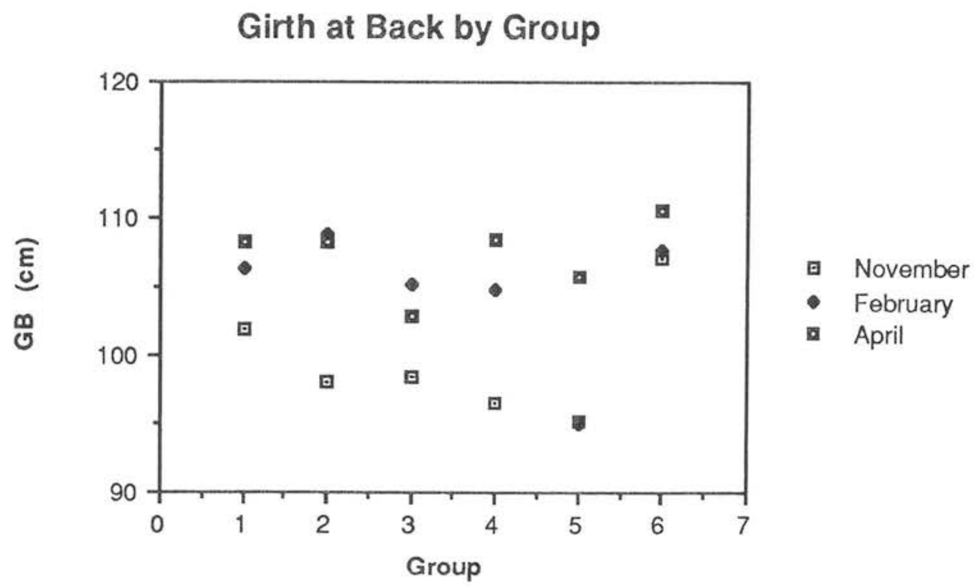


Figure 5.9 Graph of Group and Farm Least Squares Means for Girth of Animal at the Back (Abdominal Girthh; GB), Measured in November, February and April.



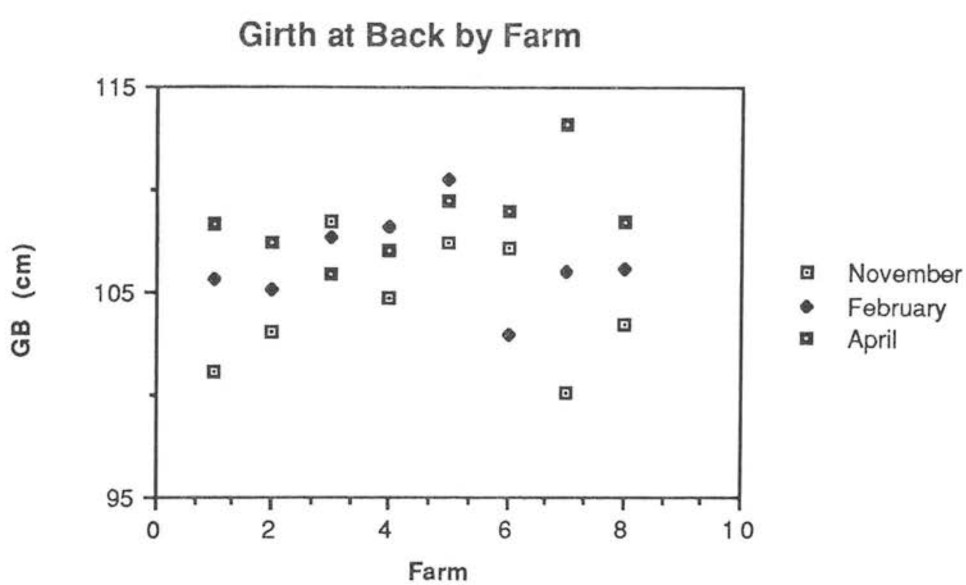
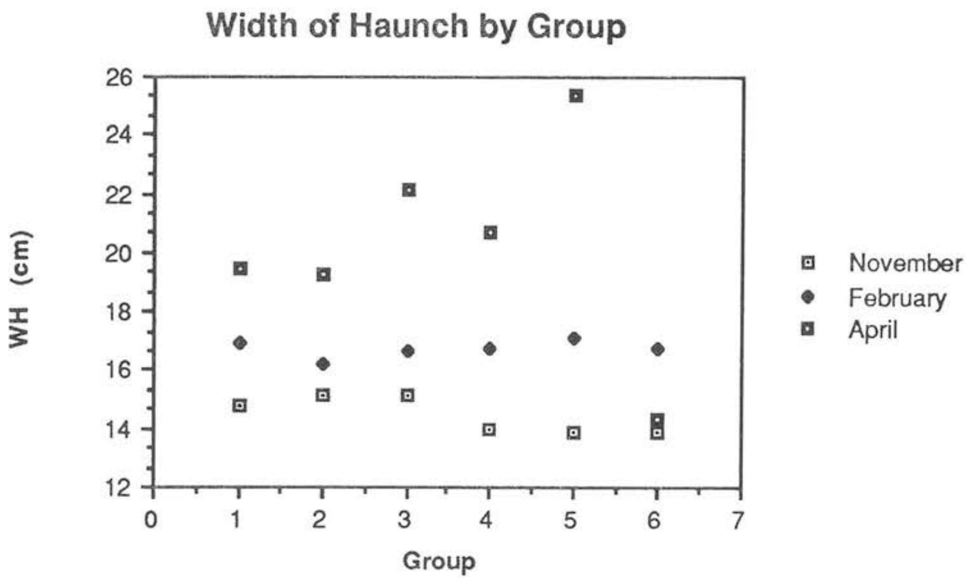


Figure 5.10 Graph of Group and Farm Least Squares Means for Width of Animal at the Haunch (WH), Measured in November, February and April.



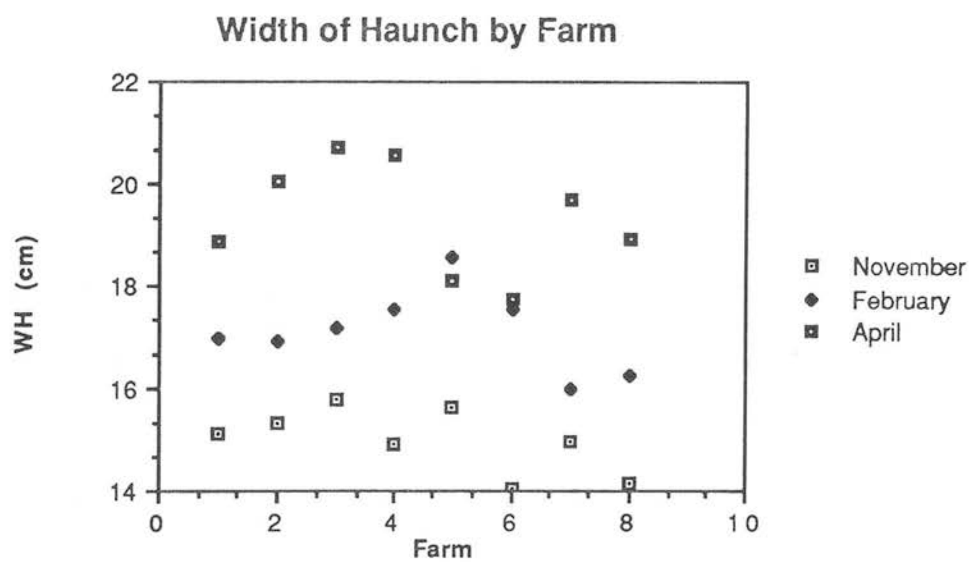
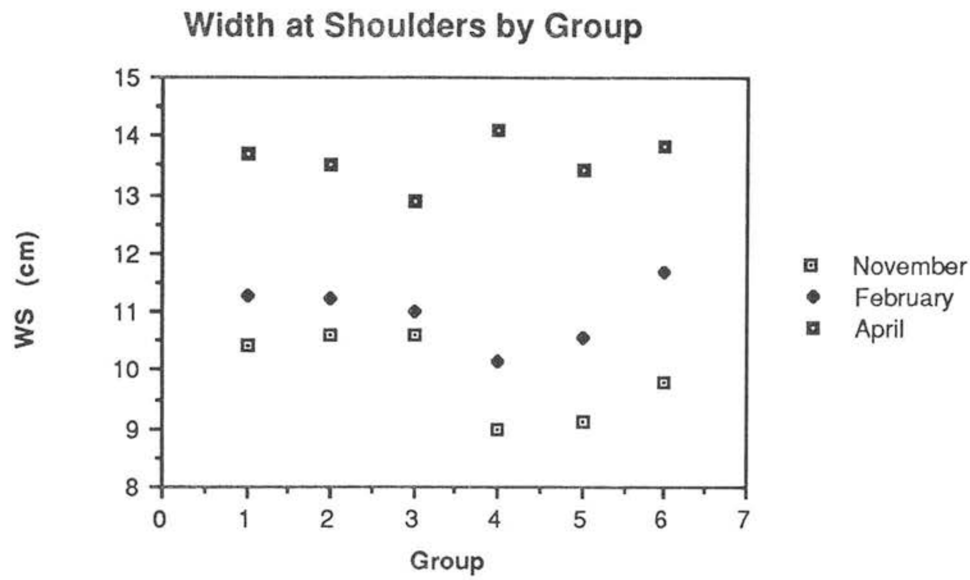
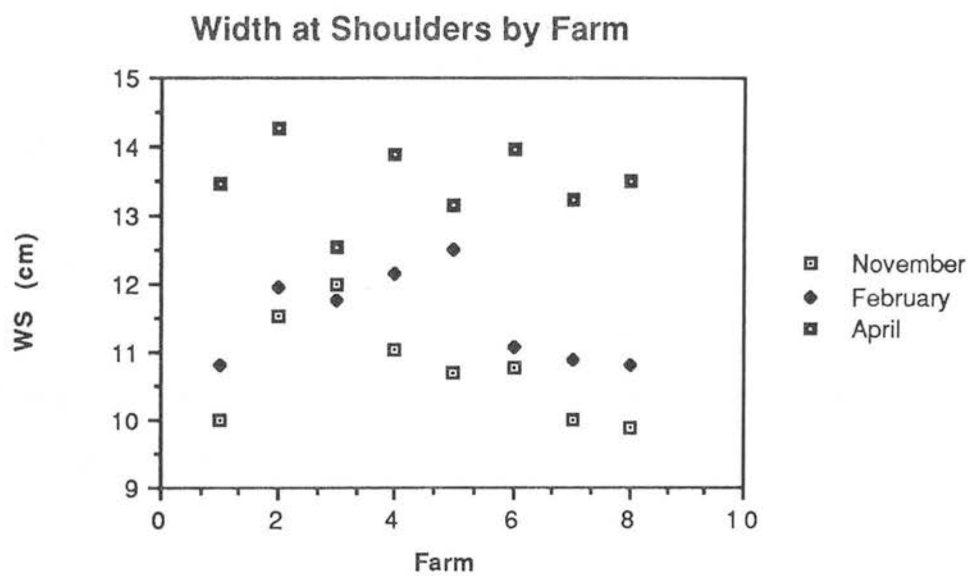


Figure 5.11 Graph of Group and Farm Least Squares Means for Width of Animal at the Shoulders (WS), Measured in November, February and April.





Group effects on linear body measurements tended not to be significant after weight was accounted for ($P > 0.05$). The exceptions were GF_F, and HBL_N. Farm effects differed between the different measurements. The significant farm effects were for HFL and HBL in February and April and WH_A, LSH_A and WS_N. In general, the variation between farm and groups for linear body measurements tends to decrease with time (except for LSH (which increases with time and HFL which shows no clear pattern).

Back Scanning

The summary results from the scanning are given in Table 5.13. Muscle and fat depths from the table are those got from the scanner. Depths are in cm. Simple regressions of these traits on liveweight and condition score are given in Table 5.14 with the correlations between these traits given in Table 5.15.

Table 5.13 Summary of Results from Back Scanning

	Wt (kg)	Muscle Depth	Fat Depth
μ	93.25	3.72	0.14
σ	6.91	0.20	0.06

Fat and eye muscle depth were poorly predicted by both weight and condition score (Figure 5.14). The best predictor was condition score for eye muscle depth. The correlations (Table 5.15) between the scan measurements and condition score and weight are in agreement with the results of the regression analysis.

Table 5.14 Simple Regression of Fat and Eye Muscle Depth on Weight (Wt) and Condition Score (CS)

Dep.	Indep.	Inter.	Slope	s.e.	R^2
Wt.	Depth	108.24	-4.03	8.23	1.31
Wt.	Fat	88.00	37.22	23.77	11.99
CS.	Depth	0.20	0.30	0.30	18.39
CS.	Fat	2.60	-0.70	1.20	2.57

Table 5.15 Correlations Between Weight, Fat and Eye Muscle Depths

	Wt	CS	Fat
Depth	-0.12	0.42	-0.33
Fat	0.35	-0.16	

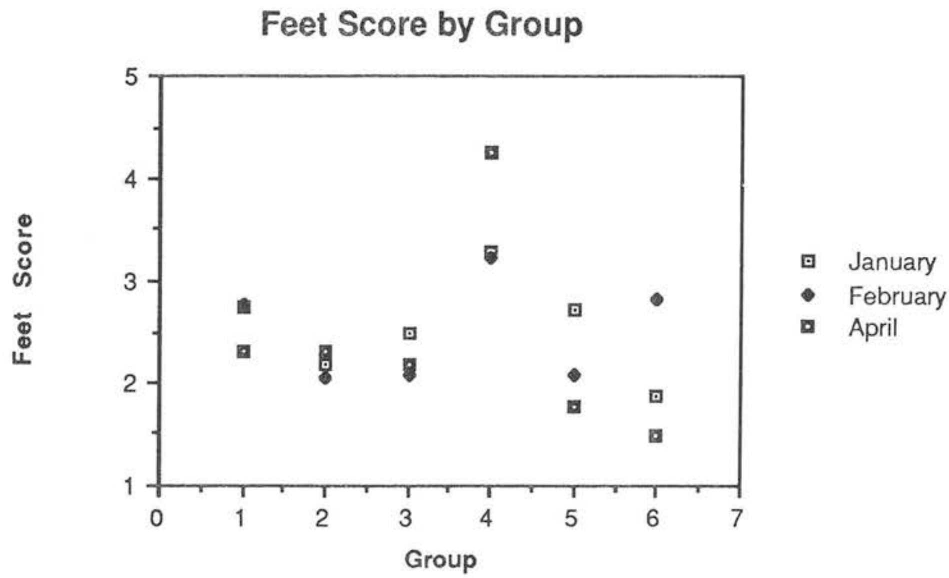
Although these animals were slaughtered the identities of the animals at slaughter were lost and no further analyses were possible. The measurement of fat and eye muscle depths using ultrasonic scanning was difficult and dangerous to carry out. This would be even more dangerous if the scanning was to be carried out at the rut. From the results presented here ultrasonic scanning is of little use for predicting composition of deer.

5.3.3 'Subjective' Traits and Antler Development

Temperament, condition score and feet were scored on a scale 1 to 5 and pedicle (antler) length was also measured three times (January, February and April). The results of these analyses are shown graphically in Figures 5.12 to 5.15 and are tabulated in Appendix III. Group effects were not significant ($P > 0.05$) for these traits (except for antler development in April ($P < 0.01$)). Farm effects tended to be significant ($P > 0.05$) for the subjective traits in January and February but was only significant ($P < 0.01$) for temperament in April. Temperament was not significant in January ($P > 0.05$).

The animals from Farm 1 had significantly worse feet than those from other farms, especially in January (Figure 5.12). Animals of Eastern European origin tended to have worse feet (especially

Figure 5.12 Graph of Farm and Group Least Squares Means for Feet Score, Measured in January, February and April



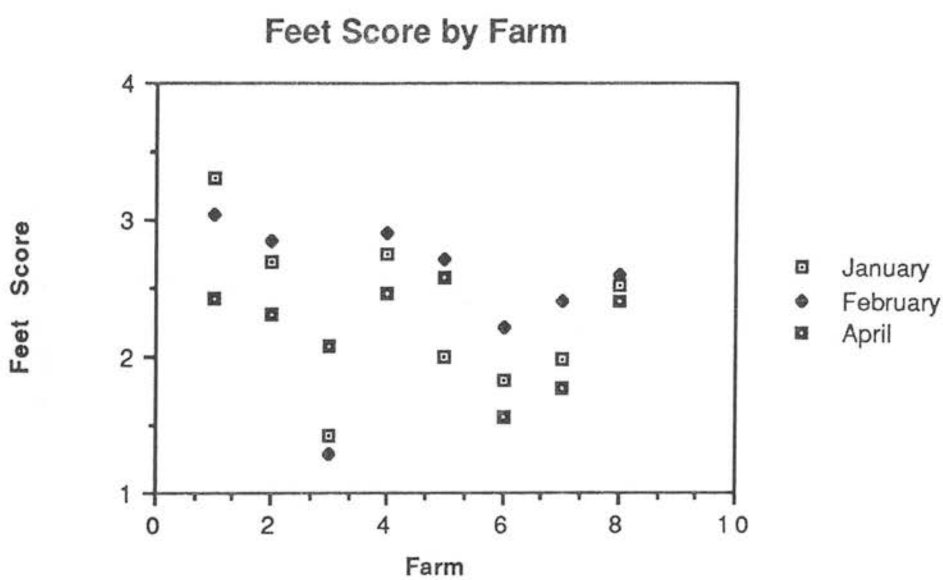
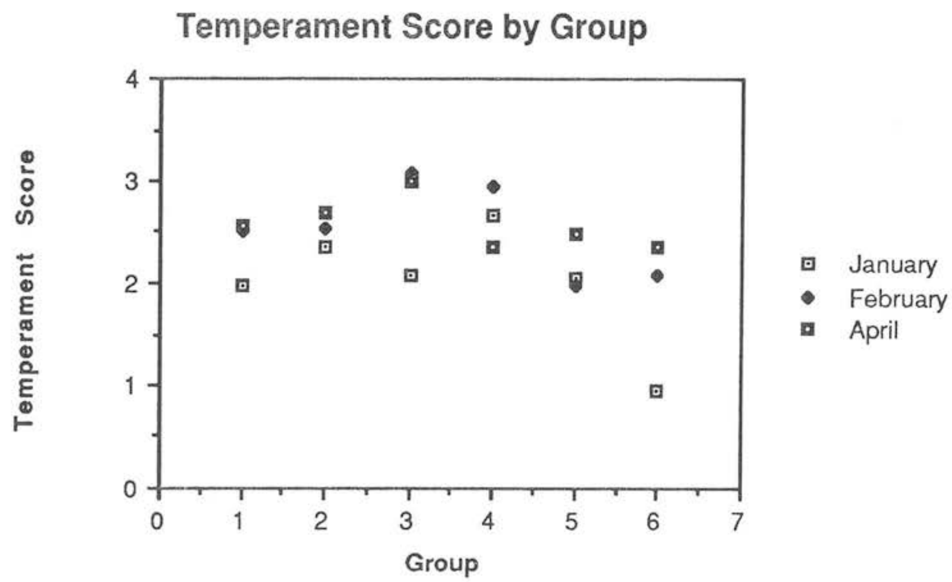


Figure 5.13 Graph of Farm and Group Least Squares Means for Temperament Score, Measured in January, February and April



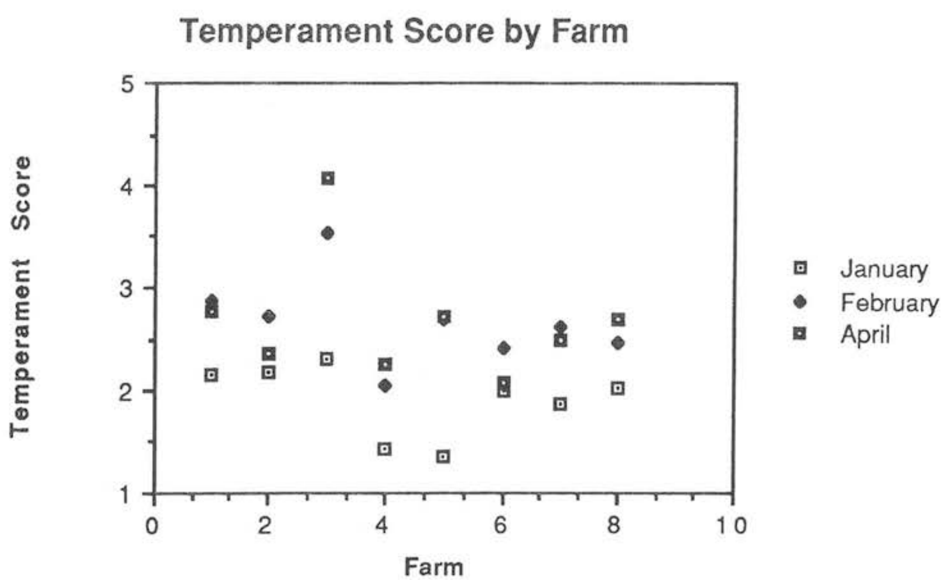
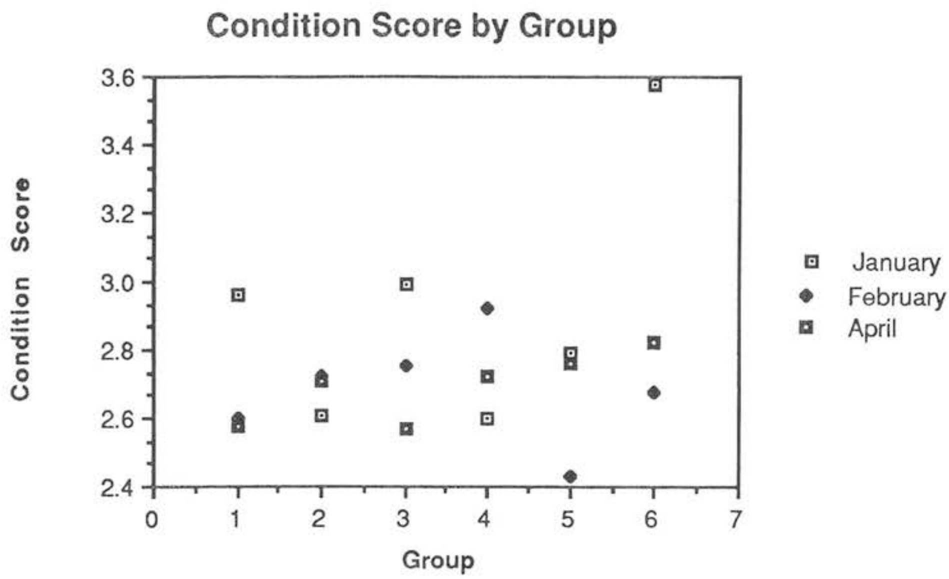


Figure 5.14 Graph of Farm and Group Least Squares Means for Condition Score, Measured in January, February and April



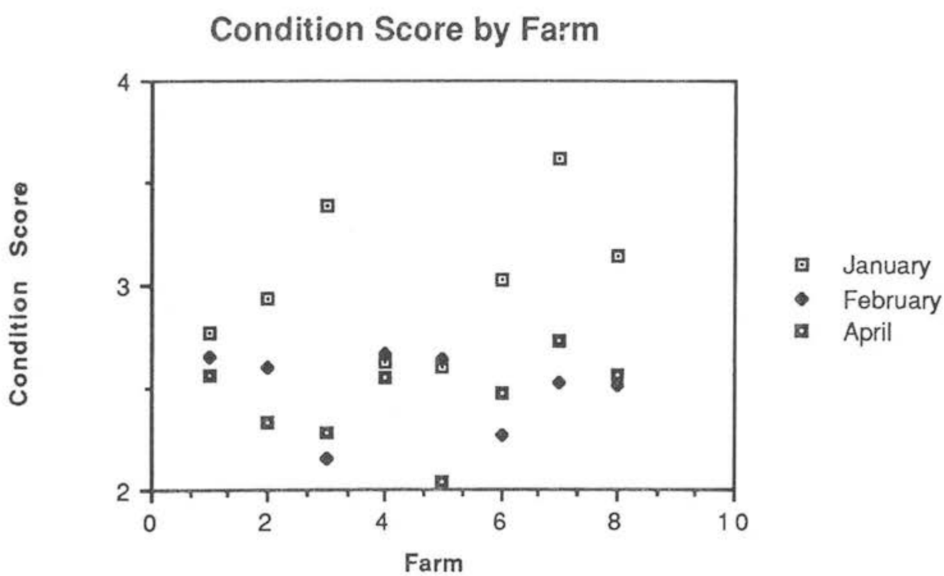
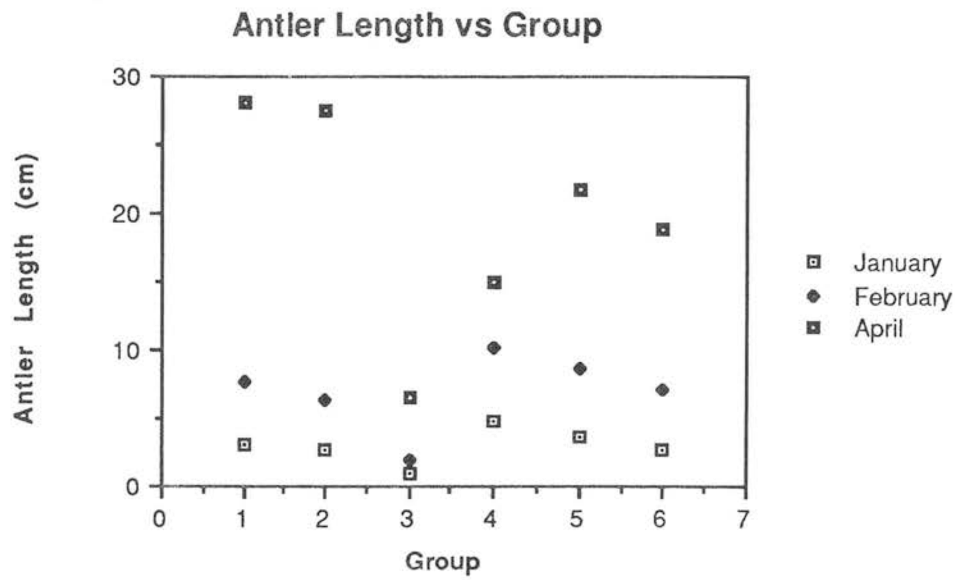
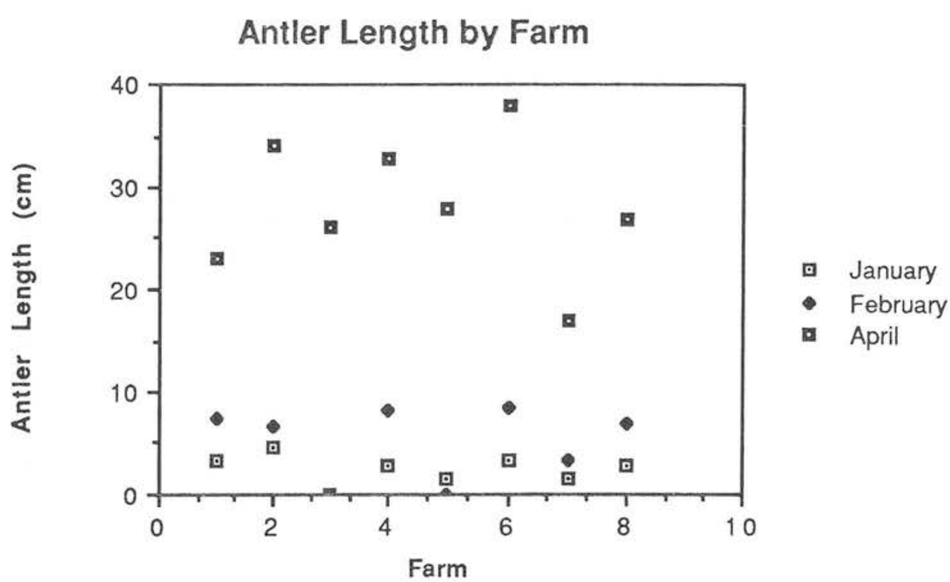


Figure 5.15 Graph of Farm and Group Least Squares Means for Antler Length, Measured in January, February and April





earlier in the test) and those of Scottish origin had better feet. Temperament was also analyzed (Figure 5.13). Farm of origin was the major factor affecting temperament. Animals from Farm 3 in particular tended to have poorer temperament, especially later in the test. Temperament scores tended to increase with time. Condition score (CS) is used as a measure of fleshing (muscle development) of animals (Figure 5.14). Farm 3 and 5 tended to have animals that were in poorer condition. This may be due to fact they were growing fast and so less time to fill out. Weight had little effect on condition score.

Pedicle development was measured as the length of the soft antler (Figure 5.15). Weight of animal on day of test had a significant effect on antler development at all ages, heavier animals tending to have longer antlers (covariates of weight on antler length were 0.08 s.e. 0.02; 0.22 s.e. 0.05 and 0.37 s.e. 0.07 for January, February and April weighings respectively). The effect of weight becomes more evident as the antlers grow. Animals from Farms 2, 4 and 6 had significantly longer antlers than animals from the other farms, and group 3 animals significantly shorter.

5.4 Discussion

The results presented here are from the first central performance test on red deer in the UK. Tong (1982) identifies the purpose of such central performance testing as to (i) performance test individual animals, (ii) estimate breeding values of prospective sires, (iii) compare herds, and (iv) provide a merchandising tool for animal sales.

This study showed that pre-test effects remain at the end of test. It cannot be determined from the data here whether or not these herd differences are genetic or environmental. The two ways which this can be determined are that sires should be represented in more than one farm and/or the pre-test period could be decreased to limit the environmental differences. The latter is being implemented for the coming year. A lower weight limit for calves entering the test is also being imposed (45kg @ 100 days of age).

BIF (1986) recommend an age range at start of test of 180 -270 days, after single-suckling with weaning at 6-10 months of age. Earlier weaning is not acceptable as it masks the dam's maternal ability (Dalton and Morris, 1978) but Wickham (1977) notes that it is difficult to make genetic comparisons between animals from different herds when animals start test at 8 or 9 months of age. The Meat and Livestock Commission (MLC, 1971) recommend 90 days of age as the latest age for the transfer of calves to the test station.

The MLC policy is to assess bulls on final weight over a fixed age range (200-400 days) (Lewis and Allen, 1974). This has been criticised because part of the record is made in an uncontrolled environment (Tong, 1982). Dalton (1981) showed that test animals could compensate for age at start of test but not for herd-induced effects. Effects of initial weight on test was found to be more pronounced than initial age effects (Tong, 1982), animals which were heavier at the start of test had a lower average daily gain. In this study there was no clear relationship between weight at start of test and gain on test.

Herd differences arise from different sources (Morris, 1981): (i) Non-genetic differences among herds having an effect on start weight, or a carry over effect on gain or final weight (ii) Genetic herd differences due to dams (iii) Genetic herd differences due to the sample of sires of the particular animals being tested. Large herds tested each year on a within-herd basis, with many progeny per sire, would be more accurate in estimating desired objectives, e.g the regression of final weight on start weight (Morris, 1981). Herd and sire will be confounded if no more than one sire per herd is used (Okanah, 1978). This is not the case with this data. To estimate genetic differences between herds or sires, 3-5 sons per sire or per herd is necessary (Collins-Lusweti and Curran, 1985; Morris, 1981).

Selection for increased post-weaning growth rate probably has contributed to the increased mature size of bulls and their progeny (Kemp, 1990). Weight at a given age is a function of birth weight, pretest gain and post test gain and so selecting for weight at a given age is likely to lead to an increased rate of maturing and a higher weight at different ages including birth and maturity (Fitzhugh, 1976). In New Zealand, authors (e.g. Carter, 1971) found that post-weaning gain had low heritability and poor predictive value for progeny liveweight production.

Therefore, in New Zealand, bulls are selected on final weight rather than test gain (Dalton and Morris, 1978), as were the animals on this test. Growth rates are used as selection criteria where feeding costs of growing stock represent a high proportion of the total costs (Barlow, 1980).

Central testing is used to select those sires which will produce the best offspring. To check on the validity of central testing, information should be gathered on the performance of the progeny of these stags and their rankings compared. This could be done on-farm provided a sample of the sires went to each farm (AI would be useful here). Within-herd performance testing is another option. Evidence on New Zealand beef cattle (Baker *et al.* 1975; Baker and Carter, 1976) suggests that this is effective on a within-farm basis, but this does not alleviate the problem of the dearth of between herd comparisons. It is hoped that the offspring of animals which have been on-test will be recorded on-farm, and some returned to test so that the validity of this test can be investigated.

As can be seen, there are many problems with central testing. Central tests lead to biassed results due to the different farms or environments from which the animals originate. These biasses have serious implications if there are large environmental differences between farms and differences persist into the test period. Ways in which these problems can be overcome are by using group breeding schemes and sire referencing schemes (James, 1976, 1978; Morris *et al.*, 1980). The use of these by deer breeders is to be encouraged, and, hopefully, they will be implemented in the near future.

Chapter 6. Breeding Objectives for Red Deer

6.1 Introduction

The profitability of any livestock enterprise affects both consumers as well as producers as production costs are reflected in sale price. In recent years farm products have failed to increase in price as much as goods from other sectors of the economy. Consequently, inflation in the farm sector (as a result of increases in prices received for farm products and prices paid for inputs bought from other areas of the farm sector) is not as high as in other sectors. Farmers do not buy all their farm inputs solely from the farm sector, therefore giving rise to a 'price-cost squeeze' on farm profits (Dickerson, 1982). There is a need, therefore, to increase the efficiency of livestock production, to help farmers increase the gross margins of their enterprises. The development of breeding programs to increase the efficiency of livestock production has been the subject of much research in recent years (Dickerson, 1982; James, 1982a; Pearson, 1982; Ponzoni, 1982; Ponzoni and Newman, 1989; Willham, 1988) and most authors agree on the need for a systematic approach to ensure that progress is optimal in the desired direction. Highly efficient selection for the wrong objective may be worse than no selection at all (James, 1982b).

A publication by Harris *et al.* (1984) outlines a nine step approach to designing comprehensive animal breeding programs. In a properly constructed programme, which is consistently followed, the scale and direction of genetic change in the traits under selection are reasonably predictable (Cunningham, 1982). Following these procedures in developing breeding programs and objectives will highlight areas where economic, phenotypic and genetic parameters are scarce and areas where research can be concentrated (Ponzoni, 1982).

The first and most important decision in any breeding program is the choice of breeding objective (Dickerson, 1982; Harris, 1970; Ponzoni and Newman, 1989). It is necessary to make a clear distinction between the selection objective and the selection criteria (James, 1982a).

6.1.1 Breeding Objective

The objective is what we wish to improve (James, 1986). It is a linear combination of economically important traits in the production system (or the aggregate genotype (Hazel, 1943)). The breeding objective should account for all the inputs and outputs of the farming enterprise. All traits which it is desirable to improve should be considered irrespective of how difficult they are to measure or how high/low their heritability is (James, 1986). This may lead to a large number of traits in the objective. Pearson (1982) suggests only including those traits which account for a significant proportion (eg 10%) of the profit. Objectives must be able to withstand minor changes in the market situation and production technology (Steine, 1982) and there should be a strong relationship between the objectives and changes in profitability (Pearson, 1982).

6.1.2 Selection Criteria

After the objective has been defined which traits can improved will be decided on the basis of genetic factors and practical questions on the design of the program, this is the choice of selection criteria. Therefore, heritability, genetic covariances between traits in the objective and ease of measurement are important in the choice of selection criteria (James, 1986). The selection criteria are the traits to be used as the indicator of the breeding value of the animal. They may or may not include the traits in the objective. The traits in the breeding objective are the 'ends' and the characters which are the selection criteria are the 'means' to achieve the ends.

6.2 Development of the Breeding Objective

In following a systematic approach deficiencies in knowledge can be pointed out and areas for further research identified (Harris *et al.*, 1984). The recommended procedure to follow in the definition of the breeding objective is outlined by Harris *et al.* (1984) and Ponzoni and Newman (1989). This includes the definition of the production system and then the formal derivation of the breeding objective, which includes the identification of the sources of income and expense, determination of the biological traits influencing income and expense and the derivation of the economic value of each trait.

6.2.1 Production system.

The stratification of the deer industry has been alluded to in earlier chapters. There are no formal crossbreeding programs nor has the uses of the different 'strains' of Red deer been defined. At the present time the use of Wapiti and animals of European parentage is very limited. For the purposes of this discussion a single production system for Red deer is assumed. The system where intervention at the genetic level is most likely to benefit the deer industry is a system of using pure Park Red Deer as both sires and dams in the breeding herd.

The life cycle of deer is described in detail in Chapter 2 and is summarised below. Hinds calve in June, at grass. A calving rate of 90% is assumed over the whole herd. Calves are weaned in September when the hinds are reintroduced to the stag. The rut lasts 2 to 5 weeks (Lincoln, 1985). Calves and hinds are generally housed over the winter period. Calves are fed 1kg concentrates/day, and *ad lib* silage or hay. Hinds are not fed concentrates until a few weeks before calving. The animals are turned out to grass in April. Standard management practices such as drenching, vaccination, tagging, TB testing and some veterinary assistance are assumed.

Calves are selected for breeding or slaughter at 15 months of age, just prior to the rut. Replacement hinds are first bred at 15 months of age. Stags are also bred at this age but at the ratio of one 15 month old stag to 10 hinds, while 6 year old and older stags can serve up to 60 hinds (depending on the terrain). For the purposes of this discussion one stag to 25 hinds is assumed.

Stag calves are sold off grass as slaughter animals at 15 to 18 months of age, when the calves weigh approximately 90kg. Hind calves are generally sold at 15 months of age as breeding animals, provided they reach the required weight for breeding purposes (Blaxter *et al.*, 1988). The products of the enterprise are therefore stag calves, surplus hind calves (not needed to replace the breeding herd) and cull hinds. All slaughter animals are assumed to be marketed through the British Deer Producers Society (BDPS).

6.2.2 Age Composition of Herd

Ponzoni and Newman (1989) state the need to identify the age and numerical distribution of the herd in defining the breeding objectives so that the number of replacements needed per year, and the number of animals in all classes available for market each year can be seen as these numbers are required for the calculation of economic values, especially since not all traits are expressed at the same frequency or at the same time. Figure 6.1 shows the herd composition. The following assumptions were made in defining the composition of a deer herd of 1000 breeding hinds:

Age of hind for culling on age = 12 years
Age of stag for culling = 8 years
Hind Mortality = 2%
Hinds culled for age or infertility = 8%
Calf Mortality 5.6%

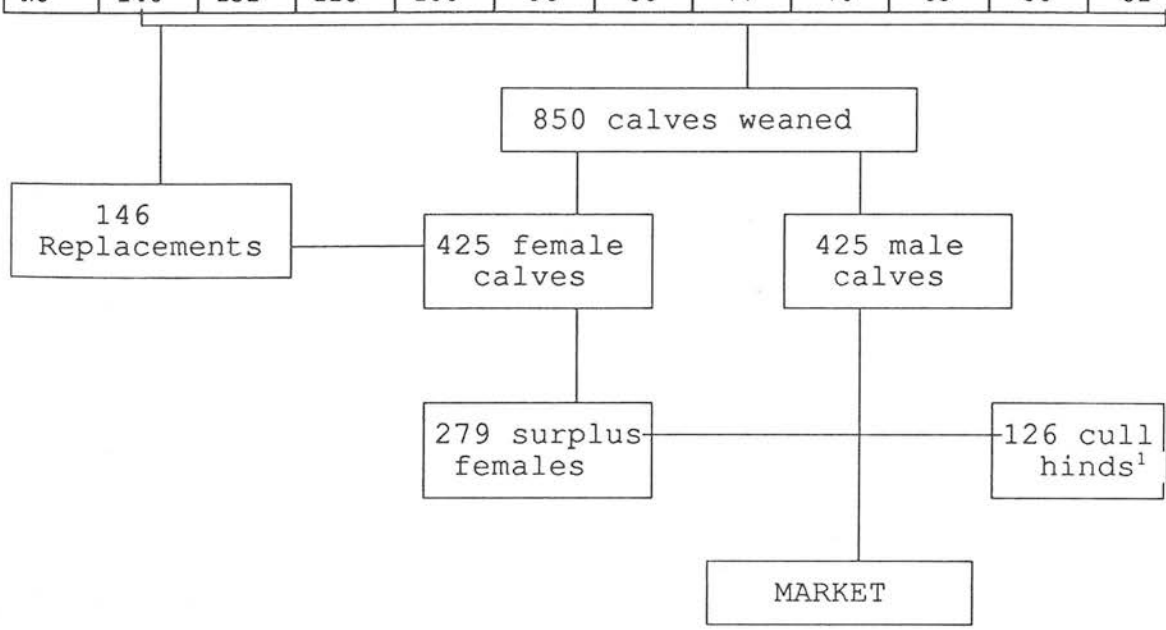
The culling of hinds due to them not calving and hind death is assumed to be an equal proportion of each year group. Therefore:

$$Herd\ Size = \frac{a(1-r^{n})}{1-r}$$

where r = 0.9 = survival, a = number of animals at 2 years of age, n = number of years in the herd

Figure 6.1. Herd Composition

Age	2	3	4	5	6	7	8	9	10	11	12
Hind No	146	131	118	106	96	86	77	70	63	56	51



[1]This includes 51 cull for age hinds and 75 other cull hinds, but does not include 20 hinds which die each year. $L_f = 5.97$; $i_f = 0.344$; $L_m = 5$

6.2.3 Identification of sources of income and expense in commercial herds and traits which influence them

Table 6.1 shows the main sources of income and expense for a deer herd, as well as the production and reproduction traits influencing these. Included in the table are traits which have clear economic benefits from their improvement. From Table 6.1 the major traits which can be identified are: number of calves weaned (NCW)), carcass weight of male calves (sCW) and cull hinds (cCW), feed consumption of hinds and offspring respectively (hFC, oFC) and disease resistance (hDR, oDR) for these two groups of animals.

Table 6.1. Sources of Returns and Costs and Traits Affecting Them.

Sources of Returns and Costs	Traits Influencing Returns and Costs
<u>Returns:</u>	
Stags for Venison	Number of calves weaned *NCW* carcass weight *sCW*
Hinds for Breeding	Number of calves weaned *NCW*, sale weight *fLW*
Cull Animals	Mature hind carcass weight *hCW*
<u>Costs:</u>	
Feed (including land)	Number of calves weaned *NCW*, feed consumption *hFC oFC*
Housing	Number of calves weaned *NCW*
Labour	Number of calves weaned *NCW*, disease resistance *cDR hDR*
Veterinary and Health	Disease resistance *cDR hDR*
Marketing	Number of calves weaned *NCW*

Costs in any farming enterprise can be variable (dependent on the level of production) or fixed (independent of the level of production). Costs listed are those which are considered to vary with the level of expression of the traits. Unlike other meat industries there is no assessment or differing price structures for carcass 'quality' (grade or fatness). This can be accredited to both the method of slaughtering and the youth of the industry.

Income can be defined as :

Number of male calves x value per individual +
Number of surplus females x value of individual +
Number of cull hinds x value of individual +
Number of cull stags x value of individual

Expense can be defined as :

<u>Feed</u>
Male calves feed intake x cost per kg +
Female calves feed intake x cost per kg +
Hind feed intake x cost per kg +
Stag feed intake x cost per kg +
<u>Husbandry</u>
Male calves husbandry costs +
Female calves husbandry costs +
Hind husbandry costs +
Stag husbandry costs +
<u>Marketing</u>
Number of male calves x marketing cost per calf +
Number of surplus female calves x marketing cost per calf +
Number of cull hinds x marketing costs per hind +
Number of cull stags x marketing cost per stag

Table 6.2 gives a balance sheet for the production system described above. Feed accounts for 57% of the variable costs in the system and only one other variable (marketing) accounts for more than 10% of the total variable costs, while the sale of cull stags account for less than 10% of the gross margin.

Table 6.2. Balance Sheet[1] for Deer Enterprise (after Hutchinson, 1990).

	Quantity	Price	Total
RETURNS		£	£
Stags (finished)	425	173.60	73 780
Hinds (breeding)	279	330.00	92 070
Cull/casualty hinds	126	120.00	15 120
stags	6	175.00	1 050
Total			182 020
COSTS			
Purchases stags	6	1000.00	6 000
Marketing		5%	9 100
Concentrates	170T	165/T	28 050
Vet/Medicine			6 000
Bedding			1 000
Fence Maintenance			5 750
Sundries (incl haulage)			7 500
Forage			19 000
Total			82 400

[1]This is based on 1000 hinds, with 850 calves reared, dead weight of stag = 56kg @ 310.00 pence per kilo, 143 forage hectares and 6.99 hinds and followers/ ha

If only those traits which account for more than 10% of the gross margin (Pearson, 1982) are included in the objective the traits which remain are:

Number of calves weaned (NCW)	
Feed Consumption:	hinds (hFC)
	offspring (oFC)
Carcass weight:	cull hinds (hCW)
	stag calves (sCW)
Liveweight	hind calves sold for breeding (fLW)

6.2.4 Derivation of Economic Values

An economic weight is the change in net return per unit change in a character. Income (I) and expense (E) can be combined in different ways to estimate the economic values of traits. These have been identified as (Harris, 1970):

i) Profit (P) = I - E

ii) Return on Investment (Φ) = I / E

iii) Cost per unit Production (Q) = E / I

The economic values are found by expressing P, Φ and Q as a function of traits in the breeding objective and using partial differentiation of P, Φ and Q with respect to the trait in question (calculated at the average for all other traits). This has the effect of linearising the function. This is done on the grounds that genetic changes are slow and so, over a short period of time, will be essentially linear (James,1986).

Not all traits in a breeding objective are expressed at the same frequency or at the same time (Ponzoni, 1986). The methods used to account for this are either to calculate income and expense in one year (accounts for frequency but not time lag) or to use discounted rates of gene flow (James, 1982a; McClintock and Cunningham, 1974; Ponzoni and Newman, 1989). This method calculates the cash flows and then discounts them back to the present value. It is necessary to do this since returns accrue at different times.

The options examined in this study included:

1) The effect of using income and expense (referred to as option 1 in future discussions) and discounting gene flow in the profit equation. Discount rates for this study were chosen at 0.00, 0.02, 0.05, 0.10, 0.15 and 0.20 (options 2 - 7 in future discussions). A period of twenty years was examined and all

generations within that 20 year period considered using method described by Hill (1974). The discount factor for year k is:

$$\mathit{Discount\ factor}\ (t) = [\frac{1}{1+r}]^k$$

where k = time in years and r = discount rate.

2) The effect of altering fixed costs on Φ and Q (where fixed costs are 0%, 10%, 30%, 50%, 75% and 100% of the gross margin of the enterprise (see Table 6.3).

Table 6.3. Income, Costs and Alternative Ways of Combining Income and Expense

Option	Income (I)	Variable Costs(a)	Fixed [1] Costs (b)	Total (E = a+b)	Profit (I-E)	Φ I/E	Q E/I
8	182 020	82 400	0	82 400	99 620	2.209	0.453
9	182 020	82 400	9 962	92 362	89 658	1.971	0.507
10	182 020	82 400	29 886	112 286	69 734	1.621	0.617
11	182 020	82 400	49 810	132 210	49 810	1.378	0.726
12	182 020	82 400	74 715	157 115	24 905	1.159	0.863
13	182 020	82 400	99 620	182 020	0	1.000	1.000

[1]Levels of fixed costs at 0%, 10%, 30%, 50%, 75% and 100% of the gross margin.

3) The effect of altering a) prices of sale animals (i) hind calves sold at the price of slaughter male calves (£3.10/kg dead carcass weight) (ii) hind and male calves sold at £2.50/kg dead carcass weight and b) altering feed costs - i.e. concentrates at £150/T and £180/T (Table 6.4). The effect of altering income and variable costs were examined using P, Φ and Q.

Table 6.4. The Effect of Altering Income and Variable Costs - Options Examined

Option	Income	Vari. Costs	Fixed Costs	Profit	Φ	Q	Notes
11	182020	82400	49810	49810	1.378	0.726	Opt.11 Table 6.4
14	124978	82400	49810	-7232	0.945	1.058	Hinds @ £3.50/kg
15	103918	82400	49810	-28292	0.768	1.272	Calv @ £2.50/kg
16	182020	79850	49810	52360	1.404	0.712	Feed £150/T
17	182020	84950	49810	47260	1.351	0.740	Feed £180/T

6.2.5 Results

The following tables give the results for the various options discussed above. All economic values are given setting hFC to -1.00 and calculating values of all other traits relative to hFC. The absolute values derived are given in Appendix IV.

Income and Expense and Discounted Gene Flow

From Table 6.5 it can be seen that as the rate of discount increases the importance of traits measured on the offspring (oFC, sCW and fLW) increases relative to the traits measured on the hinds. The change was greater the greater the discount rate applied.

Table 6.5. Relative Economic Values for Traits in Breeding Objective using Profit Equation

Trait	Income and Expense	Discounted Gene Flow					
		0.00	0.02	0.05	0.10	0.15	0.20
Option	1	2	3	4	5	6	7
NCW	10588	10588	10591	10593	10590	10592	10593
hFC	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
oFC	-1.73	-1.80	-1.95	-2.18	-2.56	-3.12	-3.66
hCW	14.96	16.16	15.78	15.23	14.50	13.89	13.33
sCW	65.19	67.95	73.43	82.47	99.27	118.02	138.02
fLW	60.74	63.32	68.43	76.85	92.49	110.00	128.61

NCW = number of calves weaned, hFC = hind food consumption, oFC = offspring food consumption, sCW = stag calf carcass weight, hLW = hind calf liveweight

Altering Fixed Costs

Tables 6.6 and 6.7 display the results for altering fixed costs on Φ and Q. When income and expense are combined as P economic values obtained are independent of fixed costs as these disappear on differentiation. This is not the case with Φ and Q. When I = E then P = 0 and Φ and Q are equal to 1. Then economic values using Φ and Q are the same and all relative economic values using the three methods are the same (subject to rounding errors). This is as predicted by Brascamp *et al.* (1985) and Smith *et al.* (1986). As fixed costs increase then NCW increases in importance relative to the other traits. This means that if more calves are born then the fixed costs will be spread over a greater number of animals.

Table 6.6. The Effect of Altering Fixed Costs using Φ to Derive Relative Economic Values

Trait	Levels of Fixed Costs ($\times 10^{-4}$)					
	0.00	0.10	0.30	0.50	0.75	1.00
Option	8	9	10	11	12	13
NCW	3415.63	4125.33	5567.89	7032.65	8767.78	10637.24
hFC	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
oFC	-1.73	-1.72	-1.73	-1.73	-1.72	-1.73
hCW	6.35	7.20	8.94	10.70	12.77	15.03
sCW	27.67	31.37	38.92	46.63	55.63	65.70
fLW	26.27	29.22	36.28	43.45	51.84	61.02

NCW = number of calves weaned, hFC = hind food consumption, oFC = offspring food consumption, sCW = stag calf carcass weight, hLW = hind calf liveweight

Table 6.7. The Effect of Altering Fixed Costs using Q to Derive Relative Economic Values

Trait	Levels of Fixed Costs ($\times 10^{-4}$)					
	0.00	0.10	0.30	0.50	0.75	1.00
Option	8	9	10	11	12	13
NCW	3409.4	4147.6	5589.8	7031.90	8834.57	10637.24
hFC	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
oFC	-1.73	-1.73	-1.73	-1.73	-1.73	-1.73
hCW	6.37	7.23	8.97	10.71	12.86	15.03
sCW	27.76	31.53	39.08	46.63	56.06	65.70
fLW	25.87	29.38	36.41	43.45	52.23	61.02

NCW = number of calves weaned, hFC = hind food consumption, oFC = offspring food consumption, sCW = stag calf carcass weight, hLW = hind calf liveweight

Altering Income and Variable Costs

The first option examined is the same as option 11 of Table 6.3 (fixed costs at 50% of the gross margin). The other 4 options studied were a reduction in hind calf price to that of stag calves (i.e. assume all animals are sold for meat rather than breeding; option 14) and that the meat price for calves falls to £2.50/kg (option 15). Options 4 and 5 look at the effect of (4) a decrease or (5) increase in the price of concentrate feed (see Table 6.4; options 16 and 17). The results from these options are given in Table 6.8 (the effect when using the profit equation), Table 6.9 (the effect when using Φ) and Table 6.10 (the effect when using Q).

Table 6.8. The Effect of Altering Income and Variable Costs on Relative Economic Values Derived Using P

Trait	1	2	3	4	5
Option	11	14	15	16	17
NCW	10588.54	5530.47	4098.18	11170.33	10388.35
hFC	-1.00	-1.00	-1.00	-1.00	-1.00
oFC	-1.73	-1.73	-1.73	-1.71	-1.82
hCW	14.96	14.96	14.96	15.78	14.68
sCW	65.19	65.19	55.66	68.77	63.96
fLW	60.74	42.80	34.51	64.08	59.59

NCW = number of calves weaned, hFC = hind food consumption, oFC = offspring food consumption, sCW = stag calf carcass weight, hLW = hind calf liveweight

Table 6.9. The Effect of Altering Income and Variable Costs on Relative Economic Values Derived Using Φ

Trait	1	2	3	4	5
Option	11	14	15	16	17
NCW	7032.65	5410.72	3936.87	7277.54	6960.46
hFC	-1.00	-1.00	-1.00	-1.00	-1.00
oFC	-1.73	-1.74	-1.73	-1.71	-1.82
hCW	10.70	15.91	22.02	11.01	10.67
sCW	46.63	69.30	92.98	47.96	46.51
fLW	43.45	45.50	44.46	45.63	42.46

NCW = number of calves weaned, hFC = hind food consumption, oFC = offspring food consumption, sCW = stag calf carcass weight, hLW = hind calf liveweight

Table 6.10. The Effect of Altering Income and Variable Costs on Relative Economic Values Derived Using Q

Trait	1	2	3	4	5
Option	11	14	15	16	17
NCW	6965.57	5386.62	3948.59	7274.86	6923.95
hFC	-1.00	-1.00	-1.00	-1.00	-1.00
oFC	-1.72	-1.72	-1.73	-1.71	-1.81
hCW	10.60	14.68	19.89	11.00	10.62
sCW	46.19	50.14	67.93	47.94	46.27
fLW	43.04	45.29	44.59	45.62	42.24

NCW = number of calves weaned, hFC = hind food consumption, oFC = offspring food consumption, sCW = stag calf carcass weight, hLW = hind calf liveweight

Table 6.8 indicates that as the price achieved for the sale of offspring decreases then the relative economic importance NCW and the offspring affected by that decrease in cost also decreases, when the profit equation is used to calculate economic values. Figures 6.9 and 6.10 show that if the price of output decreases (options 14 and 15) the relative economic value of NCW decreases but there is an increase in relative economic values of carcass traits. There is no major effect in altering variable costs (feed) on relative economic values (options 16 and 17), although as the relative values for feed consumption increases (decreases) the relative values of all other traits decreases (increases), except for oFC.

In addition, 2 further herd structures were examined to see the effect of changing herd structure on economic values. These were keeping breeding females for 8 years and breeding keeping females for 4 years. The number of animals in each class for sale given each of the three herd structures above (including the original herd) were:

	Herd Structure		
	1	2	3
No. Male Calves	425	425	425
No. Female Calves	146	249	134
No. Cull Hinds	126	156	271

(where herd structure 1 = hinds kept for 11 years 2 = hinds kept for 8 years and 3 hinds kept for 4 years)

Economic values were again derived for each trait in the selection objective and discounted at 5% as described above. The economic values derived are given in Table 6.15.

Table 6.15 Economic Values Derived using Differing Herd Structures (Relative economic values in brackets)

	Herd Structure		
Trait	1	2	3
NCW	97035	108358.9	128485.6
	(10593)	(10696.8)	(10698.2)
hFC	-9.16	-10.13	-12.01
	(-1.00)	(-1.00)	(-1.00)
oFC	-20.00	-20.95	-22.58
	(-2.18)	(-2.07)	(-1.88)
hCW	139.54	169.66	395.44
	(15.23)	(16.75)	(32.93)
sCW	755.39	812.30	894.91
	(82.47)	(80.19)	(74.51)
fLW	703.91	675.49	400.49
	(76.85)	(66.68)	(33.35)

NCW = number of calves weaned, hFC = hind food consumption, oFC = offspring food consumption, sCW = stag calf carcass weight, hLW = hind calf liveweight

As the number of years for which hinds are kept in the herd decreases then the relative importance of hind traits increases. The correlations between the objectives obtained for the different herd structures were 0.999 (between 1 and 2), 0.993 (between 1 and 3) and 0.996 (between 2 and 3). It is apparent that the objectives are relatively stable over different herd structures.

6.3 Correlations between Objectives and Criteria

The relationships between the various selection objectives shown above can be examined using selection index theory. Reviews of selection index theory and principles can be found in Cunningham (1972), Ronningen (1974) and Hill (1981). A brief summary is given in James (1982b) and it is this form that is given below.

Suppose that there are m traits of economic importance, i.e. in the selection objective ($Y_1 \ldots Y_m$) and n traits to be used in selection ($X_1 \ldots X_n$) i.e. selection criteria. Some of the traits may be among the Y's and not the X's and vice versa.

Let:

H = aggregate breeding value (selection objective)
I = selection index
P = n x n phenotypic covariance matrix of X's
Q = m x m genetic covariance matrix of Y's
G = n x m genetic covariance matrix between Y's and X's
a = vector of economic weights (H = a'y)
b = vector of index coefficients (I = b'x)
y and x are vectors of Y's and X's

Then:
Optimum index weights
$$b = P^{-1}Ga$$
Variance of index
$$\sigma^2_I = b'Pb = a'G'P^{-1}Ga$$
Variance of breeding values
$$\sigma^2_H = a'Qa$$
Correlation between index (I) and breeding objective (H)
$$r_{HI} = \sigma_I/\sigma_H$$
Response to selection with standardised selection differential i
$$R_{H.I} = ir_{HI}\sigma_H = i\sigma_I$$
Correlation between two different objectives H_1 and H_2 with economic weights a_1 and a_2
$$r_{H1H2} = a'_1Qa_2 \ /[(a_1'Qa_1)(a_2'Qa_2)]^{0.5}$$
Correlation between indices I and I_1
$$r_{I\ I1} = b'Pb \ /[(b'Pb)(b_1'P_1b_1)]^{0.5}$$
The efficiency of I_1 to predict I for improving H is given by $r_{I.I1}$
Response in individual traits (Y_i) in the objective selected on index (I)
$$CR_{Yi} = b'G/\sigma^2{}_I$$

The phenotypic and genetic parameters used in this study are based on those estimated in Chapters 3 and 4 of this thesis. In some cases there was little or no information on some of the traits or relationships between the traits. For example, there is very little information available on feed intake on deer. Information was then taken from other species of animals. References used include Cameron (1988); Wolf *et al.* (1981), Theissen (1985), MacNeil (1988) and Bishop (1990). The heritabilities and correlations used are shown in Table 6.11.

Table 6.11 Genetic and Phenotypic Parameters used in the Calculation of Breeding Objectives and Selection Criteria for Red Deer

	NCW	hFC (T/DM/yr)	oFC (T/DM/yr)	hCW (kg)	sCW (kg)	fLW (kg)
μ	0.85	0.93	0.65	50	56	75
σ	0.36	0.09	0.07	8.50	8.50	8.50
Heritabilities (on diagonal), Phenotypic (above diagonal) and Genetic Correlations (below diagonal)						
NCW	**0.07**	0.30	0.15	0.30	0.15	0.15
hFC	0.40	**0.26**	0.60	0.60	0.60	0.60
oFC	0.25	0.50	**0.27**	0.60	0.60	0.60
hCW	0.25	0.60	0.50	**0.26**	0.70	0.80
sCW	0.20	0.50	0.70	0.80	**0.30**	0.90
fLW	0.20	0.50	0.70	0.80	0.90	**0.40**

NCW = number of calves weaned, hFC = hind food consumption, oFC = offspring food consumption, sCW = stag calf carcass weight, hLW = hind calf liveweight

To get from a heritability / correlation matrix to a variance / covariance matrix the following assumptions were used:

Genetic covariance between traits 1 and 2 = $r_A h_1 h_2 \sigma_1 \sigma_2$

Genetic variance of trait i = $h^2_i \sigma^2_i$

Phenotypic covariance between traits 1 and 2 = $r_P \sigma_1 \sigma_2$

Phenotypic variance of trait i = σ^2_i

where: r_A and r_P are the genetic and phenotypic correlations respectively; h^2_i is the heritability of trait i and σ^2_i is the phenotypic variance of trait i.

Objectives

Table 6.12 shows the correlations between options shown in Tables 6.4 - 6.6 above while Table 6.13 shows the correlations between options shown in Tables 6.8 - 6.9. It can be seen that correlations between objectives are very high (all are greater than 0.92) and generally very close to 1 (or -1 if the correlations between economic values calculated by using Q and either P or Φ). The correlations are highest between adjacent situations from each of the options described above (e.g correlations between options 5 and 6 are greater than between options 4 and 6). Correlations between objectives using Q or Φ are 1. Since the correlations between all objectives are very high it is recommended that P should be used as the method of calculating economic values as it is simplest method. Since, in theory, returns and costs should be discounted the chosen rate is 0.05 (Bird and Mitchell, 1980). All further calculations will be made using this rate.

Criteria

Information for selection comes from several sources (the individual, its sibs, the dam, sire and other relatives). Three selection indices were constructed using 1) all the traits in the objective; 2) omitting food consumption (hFC and oFC); and 3) omitting food consumption and carcass data (hCW and sCW), and using information from various different family structures. Table 6.14 shows the family structure (A) selected to estimate the first selection index. Further selection indices were constructed by B) doubling and C) tripling number of half sibs

Table 6.13a Correlations Between Different Breeding Objectives with Economic Weights Estimated by Different Methods and Altering Fixed Costs

Option	1[1]	2	3	4	5	6	7	8[2]	9	10	11	12	13
2[1]	0.999												
3	0.999	0.999											
4	0.997	0.998	0.999										
5	0.990	0.992	0.996	0.998									
6	0.979	0.982	0.988	0.992	0.998								
7	0.966	0.970	0.978	0.983	0.993	0.998							
8[2]	0.995	0.996	0.999	0.999	0.999	0.995	0.987						
9	0.997	0.998	0.999	1.000	0.998	0.992	0.983	0.999					
10	0.999	0.999	1.000	0.999	0.995	0.987	0.977	0.998	0.999				
11	0.999	0.999	0.999	0.999	0.993	0.984	0.972	0.997	0.999	0.999			
12	0.999	1.000	0.999	0.998	0.991	0.981	0.968	0.996	0.998	0.999	0.999		
13	1.000	0.999	0.999	0.997	0.990	0.979	0.966	0.995	0.997	0.999	0.999	0.999	
8[3]	-1.000	-0.996	-0.999	-0.999	-0.999	-0.994	-0.987	-1.000	-0.999	-0.999	-0.997	-0.996	-0.995
9	-0.997	-0.998	-0.999	-1.000	-0.998	-0.992	-0.983	-0.999	-1.000	-0.999	-0.998	-0.998	-0.997
10	-0.999	-0.999	-1.000	-0.999	-0.995	-0.987	-0.977	-0.998	-0.999	-1.000	-0.999	-0.999	-0.999
11	-0.999	-0.999	-0.999	-0.999	-0.993	-0.984	-0.972	-0.997	-0.997	-0.999	-1.000	-0.999	-0.999
12	-0.999	-1.000	-0.999	-0.998	-0.991	-0.981	-0.986	-0.996	-0.998	-0.999	-0.999	-1.000	-0.999
13	-1.000	-0.999	-0.999	-0.997	-0.990	-0.979	-0.966	-0.995	-0.997	-0.999	-0.999	-0.999	-1.000

	8[3]	9	10	11	12
9[3]	0.999				
10	0.999	0.999			
11	0.997	0.999	0.999		
12	0.996	0.998	0.999	0.999	
13	0.995	0.997	0.999	0.999	0.999

[1] Refers to options 1 to 7 calculated using Income and Expense and Discounted Gene Flow (Table 6.6)
[2] Refers to options 14 to 18 calculated using economic values derived from Φ (Table 6.7)
[3] Refers to options 14 to 18 calculated using economic values derived from Q (Table 6.8)

Table 6.13b Correlations Between Breeding Objectives Using Alternative Methods of Calculating Economic Values and Alterating Income and Variable Costs

Option	11[1]	14	15	16	17	11[2]	14	15	16	17	11[3]	14	15	16
14[1]	0.983													
15	0.972	0.999												
16	1.000	0.983	0.972											
17	1.000	0.983	0.972	1.000										
11[2]	0.999	0.987	0.977	0.999	0.999									
14	0.976	0.999	0.999	0.976	0.976	0.982								
15	0.920	0.977	0.987	0.920	0.920	0.930	0.983							
16	0.999	0.987	0.978	0.999	0.999	1.000	0.982	0.931						
17	0.999	0.987	0.977	0.999	0.999	1.000	0.982	0.930	1.000					
11[3]	-0.999	-0.987	-0.977	-0.999	-0.999	-1.000	-0.982	-0.930	-1.000	-1.000				
14	-0.988	-0.999	-0.996	-0.988	-0.988	-0.992	-0.998	-0.969	-0.992	-0.991	0.992			
15	-0.944	-0.989	-0.995	-0.944	-0.944	-0.952	-0.993	-0.997	-0.953	-0.952	0.952	0.984		
16	-0.999	-0.987	-0.978	-0.999	-0.999	-1.000	-0.982	-0.931	-1.000	-1.000	1.000	0.992	0.953	
17	-0.999	-0.987	-0.977	-0.999	-0.999	-1.000	-0.982	-0.930	-1.000	-1.000	1.000	0.991	0.952	1.000

[1] Refers to economic values calculated using P (Table 6.9)
[2] Refers to economic values calculated using Φ (Table 6.10)
[3] Refers to economic values calculated using Q (Table 6.11)

(including sibs of parents). Full sib information was then included using 5 full sibs (and D) 20, E) 40 and F) 60 half sibs) and G) 20 full sibs with 20 half sibs per family group. The accuracies of selection with the different selection indices are in Table 6.15. and the correlations between the different indices given in Table 6.16.

Table 6.14 Characters in the selection objective and information assumed available from relatives

Characters	Relatives
NCW	Dam (5/4/3 records) 4 half sisters (1 record)
fLW	individual 20/40/60 half sibs (5/10 full sibs)
hCW	5/10/15 paternal half sisters 5/10/15 maternal half sisters
sCW	10/20/30 half sibs (5/10 full sibs)
hFC	dam (5/4/3 records) 10/20/30 half sisters (1 record)
oFC	individual 20/40/60 half sibs (5/10 full sibs)

NCW = number of calves weaned, hFC = hind food consumption, oFC = offspring food consumption, sCW = stag calf carcass weight, hLW = hind calf liveweight

Table 6.15 Accuracy of Selection Indices

	Selection Index		
	1	2	3
A	0.551	0.534	0.530
B	0.559	0.547	0.543
C	0.571	0.560	0.555
D	0.568	0.558	0.556
E	0.579	0.569	0.567
F	0.589	0.580	0.577
G	0.590	0.583	0.577

where 1 is an index using all the traits in the objective; 2 is omitting food consumption and 3 is omitting food consumption and carcass information. A - G are described in the text (A-C have information from half sibs only; D-E have information from 5 full sibs and G has information from 20 full sibs)

The accuracies of the selection index increases with more traits in the selection index and increased information from relatives.

There is a very small increase in accuracy using 20 full sibs as opposed to 5 full sibs, particularly when half sib numbers are high.

Table 6.16 Correlations Between Different Selection Indices

	1 & 2	1 & 3	2 & 3
A	0.968	0.961	0.993
B	0.980	0.972	0.992
C	0.981	0.973	0.991
D	0.983	0.979	0.996
E	0.984	0.979	0.995
F	0.985	0.980	0.995
G	0.987	0.978	0.991

Table 6.16 indicates that indices 2 and 3 are highly correlated with each other. This indicates that after measurement of liveweight, most of the information would come from measuring food consumption. The correlated responses for the traits in the objective using each of the three selection indices, using the first family structure above are given in Table 6.17.

	Index		
Trait	1	2	3
NCW ($\times 10^{-6}$)	3.61	3.47	3.63
fLW ($\times 10^{-4}$)	4.52	4.69	4.67
hCW ($\times 10^{-4}$)	3.07	3.20	3.10
sCW ($\times 10^{-4}$)	3.65	3.77	3.66
hFC ($\times 10^{-6}$)	3.50	2.31	2.30
oFC ($\times 10^{-6}$)	2.81	2.43	2.42

(Selection index 1 includes all traits; 2 omits food consumption and 3 omits food consumption and carcass weights; NCW = number of calves weaned, hFC = hind food consumption, oFC = offspring food consumption, sCW = stag calf carcass weight, hLW = hind calf liveweight)

Removal of food consumption from the selection index decreases the response in food consumption and increases the response in liveweight and carcass traits. Further removal of carcass information has little effect in the response in food consumption but causes a decrease in the response to carcass weight.

6.3 Discussion

The estimation of economic weights is difficult as relative costs and prices fluctuate periodically. With a 50% error or change in the economic weight of any of the traits there was a less than 2% decrease in the predicted efficiency of selection (Fowler *et al.*, 1976) and less than 1% in the study by Vandepitte and Hazel (1977). Errors in correlations and heritabilities gave a similar result. Therefore the efficiency of the index is relatively insensitive to large changes in economic weights. Ronningen (1971) concluded that the loss in efficiency is not too serious when moderate deviations from the true economic ratio are used.

The question arises as to which one of the methods for estimating economic values is the most appropriate way of combining income and expense. Opinions vary in the literature. Morris (1981) pointed out that profit was the major incentive for change in the farming business and this should be used as the selection objective. Smith *et al.* (1986) state that real profit comes from decreasing the cost of production per unit of product value (i.e. Q) and James (1982) suggests that in the long term the efficiency of production (Φ and Q) is the appropriate criterion.

Prices per unit output follow the cost of production (Dickerson, 1982), eg an increase in production costs can lead to an increase in product cost. On the other hand, a decrease in production costs may not lead to differences in prices. This can then lead to an increase in profit (James, 1982a), at least in the short term. James (1982a) suggests that when the product market is limited and output cannot be increased Φ should be the criterion while when input is fixed Q should be the criterion. Smith *et al.* (1986) and James (1986) conclude that (ii) or (iii) are more appropriate since profit contains a component that could be matched by rescaling the enterprise without any genetic improvement, but the difference between these different methods may only have a small effect in practice (Smith *et al.*, 1986). Brascamp *et al.* (1985) and Ponzoni (1988) show that if profit is set to zero then all 3 methods are the same, and using (i) is preferable because of its simplicity. Results from this study concur with this conclusion. P is unaffected by levels of fixed costs and while many farms may have similar gross margins, fixed costs may vary markedly also making P the preferred method of calculating economic values.

A selection index is a linear combination of the observed measurements, constructed so as to maximise the correlation with breeding value (Sales and Hill, 1976). The maximum response can only be achieved if the underlying genetic and phenotypic parameters are known with precision. In this case, estimates of many of the genetic and phenotypic parameters are approximations from other species of animals and so further investigations into response to selection with alternative selection indices was not investigated. In the future selection indices will be obsolete and breeding animals chosen using Best Linear Unbiased Prediction (BLUP).

Using this method of deriving breeding objectives for Red deer it is apparent that there are several areas where our knowledge is deficient and where future research can be concentrated. The estimation of genetic and phenotypic parameters for many traits will have to be investigated. These traits include carcass traits and traits involved in feed efficiency and feed consumption. More accurate estimates of parameters for growth traits is also needed. The development of alternative selection objectives when using breeding stock from Eastern Europe and Wapiti animals in pure-bred and cross-breeding schemes may be appropriate, but further information is required on production characteristics from these animals. In the future, if the deer industry develops a grading system for carcasses, with a differential pricing system, these breeding objectives will have to be revised, although this is not envisaged for quite some time.

At the moment, many farmers are selecting animals on the basis of body or antler size, which are purely subjective measures. Antlers have no intrinsic value in the UK and should not be included in the breeding objective unless it could be shown that a measure of antler size would improve the accuracy of selection for the economic breeding objective. Selection for weight is a the more accurate way of selecting for 'size', and faster progress in the breeding objective can be achieved if it is measured objectively. Breeding objectives for deer in New Zealand include number of calves born, liveweight at 12 months and velvet weight at 24 months (Rapley, pers comm).

In comparison with breeding objectives for Red deer in New Zealand objectives estimated here have similar weights, although food consumption is not included in the New Zealand estimates. When these objectives are compared with those for sheep and beef the values for food intake are similar (Ponzoni, 1988; Ponzoni and Newman, 1989). Offspring carcass weights for deer have higher economic weights than those for cattle (x 1.5) but they are of similar order when the prices achieved for deer calves are decreased (options 14 and 15). The economic value for sheep carcass weight is about half that for beef and deer carcass weight. The major difference between the economic weights for deer and for other species is the value for number of calves weaned (NCW). It is 10 times higher than the corresponding value for sheep (Ponzoni, 1988) and 50 times larger than the corresponding value in cattle (Ponzoni and Newman, 1989) when the price of venison is decreased. The reason for the difference is likely to be the fact that deer farming tends to be a more profitable enterprise than beef or sheep farming, and so increasing the number of calves born and therefore sold will have a major effect on the profit.

The deer farming industry would benefit greatly from a recording scheme run by an independent body which would collect and analyze information from on-farm records. Abattoir slaughtering may make it easier to obtain carcass information necessary for the calculation of breeding objectives. The establishment of genetic links between farms using reference sires or group breeding schemes would also be a major step in obtaining more accurate estimates of genetic and phenotypic parameters for use in the development of breeding objectives for deer herds.

Chapter 7. Liveweight and Carcass Trait Prediction From Linear Body Measurements and Profile Areas

7.1 Introduction

Ease of measurement and definition has meant that weight has been used as the most common measure of growth in animals and as an estimate of the subsequent monetary value of the carcass. Weight does not give information on different body proportions or take account of fluctuations in gut-fill. Animals of the same weight are likely to vary in their various body measurements such as heights, widths, lengths and girths. Linear body measurements have been used in several species to estimate certain aspects of animal liveweight (Owen *et al.*, 1977; Bhat *et al.*, 1980; Jones *et al.*, 1989), growth and shape (Brown *et al.*, 1973; Fisher, 1975a; Chapter 8, this thesis). Linear body measurements have been used for other purposes. Hip measurements have been used to estimate age in heifers (Krahmer and Jahn, 1969) and milk yield in cows (Rao and Venkayya, 1973). Conversely, prediction of body measurements from weight for use in the design of housing has also been studied (Sharples and Dumelow, 1990).

Knowing the weight of animals is important for the administration of anaesthetics, antibiotics, anthelminthics and other drugs, and for feeding recommendations. Selection of animals for slaughter can be by weight (eg Blaxter *et al.*, 1988) as well as by condition. Breeding success can also be, in part, dependent on weight (McManus and Hamilton, 1991).

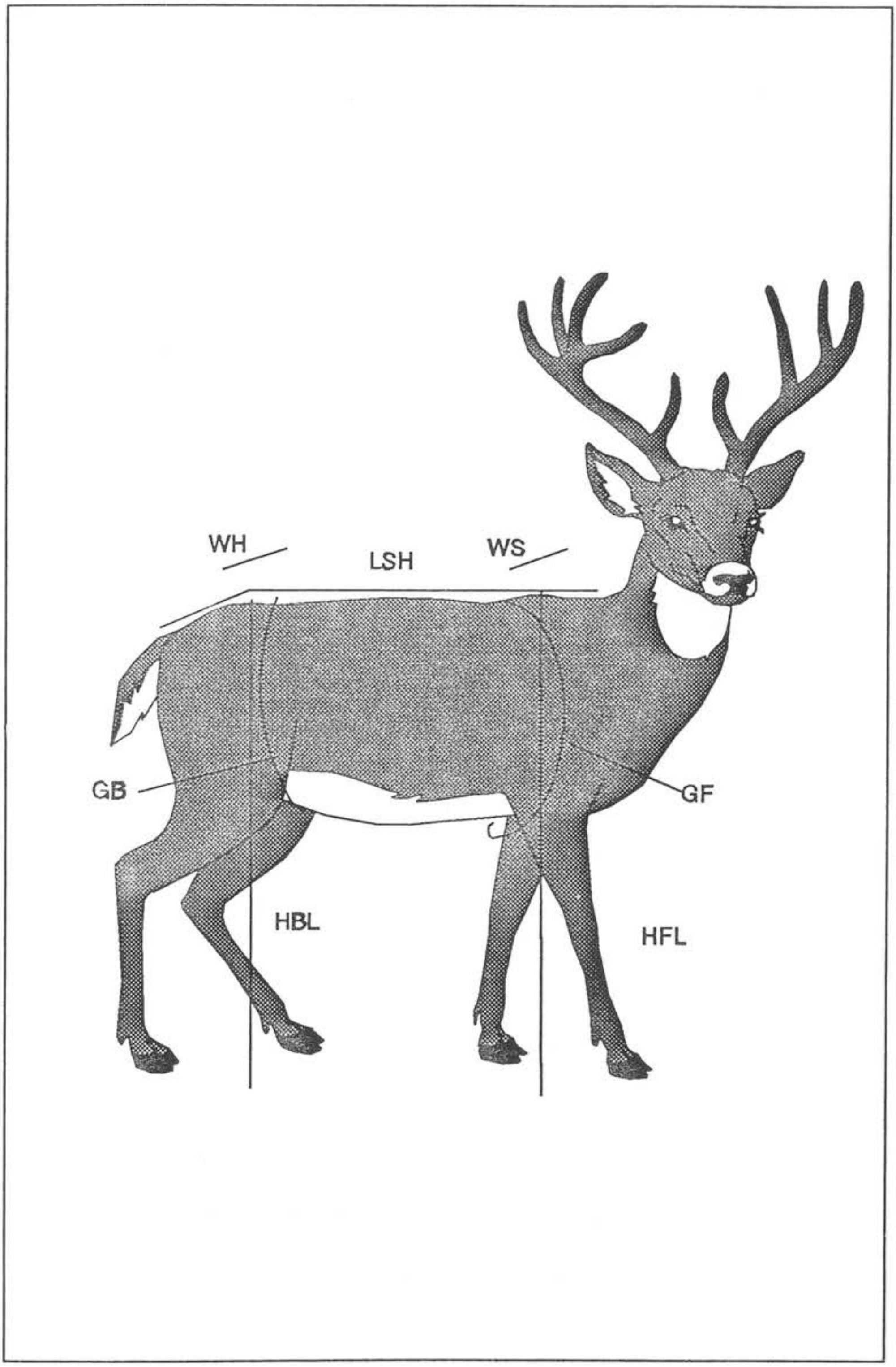
The production of venison is the major objective of the deer industry. The high priced cuts are chiefly in the hindquarter of the animal. The use of visual appraisal of meat animals in other species to judge the value of the carcass is well known. This is a subjective system dependent on the ability of the scorer. It is desirable for breeders to have an objective method of predicting certain carcass traits from measurements taken on the live animal. Body measurements have been incorporated into prediction equations for fatness (Brown and Shrode, 1971) and related to traits on the carcass or weights of various joints (Cook *et al.*, 1951; White and Green, 1952; Orme *et al.*, 1959). Profile areas of beef carcasses have been used to attempt to predict carcass composition (Fisher, 1975b).

This chapter investigates the accuracy of prediction of the liveweight of red deer at birth and slaughter, as well as certain carcass traits, using linear body measurements and profile areas on the live animal. The relationships between different measurements are also examined using correlation and principal component analyses.

7.2 Materials and Methods

Eight linear body measurements and weights were taken on 39 stags at Rosemaund Experimental Husbandry Farm in the winters of 1989 and 1990. The stags were approximately 16 months of age. The measurements were taken with either a pair of callipers or a flexible tape. Figure 7.1 shows a diagram of the measurements made on the animals.

Figure 7.1 Linear Measurements Made on Stag Calves



HBL = Height at Back Leg; HFL = Height at Front Leg, GF = Girth at Front, GB = Girth at Back, WS = Width of Shoulders, WH = Width of Haunch, LSH = Length from Shoulder to Haunch

The animals were not used to close human contact. Some of them became quite restless making it difficult to ensure that they were positioned 'normally' for measurement, i.e. legs vertical, back straight, the stance recommended for measuring purposes (Touchberry and Lush, 1950). Height of the withers (HFL) was measured as the highest point over the scapulae vertically to the ground. Height of the haunch (HBL) was measured as the height point over the hook bones vertically to the ground. Heart girth (GF) was measured as the smallest circumference posterior to the forelegs at right angles to the body axis. Rear flank girth (GB) was measured as the smallest circumference just anterior to the hind legs in a vertical plane. Hook width (WH) was measured as the distance between the prominent projections of the hip (hook) bones. Width of shoulders (WS) was measured as the distance between the prominent projections of the scapula. Length from mid point between shoulders to mid point between hook bones (LSH) was also measured as well as the weight of the animal. Weight was measured in kg while all other measurements were in cm.

After weighing animals were photographed in a 'normal' position close to a wall which was used to scale the photographs. Areas of each body portion (foreleg, lumbar/abdominal region, hindleg and whole) were calculated using an image analyzer and a light pen to draw around the area. Three photos of each animal were used and the areas averaged.

Nineteen of these stags were sent to the Meat Research Institute in Bristol for a total carcass dissection. Deer were slaughtered at approximately 16 months of age in October to December.

7.2.1 Statistical Analysis

The relationship between weight and linear dimensions was analyzed by regression. Initially the relationship between each linear measurement and weight was investigated using simple linear regression using the equation:

$$Wt = bM + c$$

where:
Wt = Body weight (kg)
M = Linear Body Measurement (cm)
c = intercept of regression line with the Y axis
b = slope of the regression line

and

$$b = \Sigma mw / \Sigma m^2$$

where:
w = deviation of each Wt value from the mean Wt value
m = deviation of each M value from the mean M value

This was also carried out using cubed values and logs of the linear measurements. Several authors (Fisher, 1975b; Petherick, 1982; Cermak, 1983) have suggested that the linear dimensions are related to the weight of an animal by:

$$Wt = bM^3 + c$$

where:
Wt = Body weight
M = Linear body measurement

Multiple linear regression was then used to investigate the relationship between all the linear measurements and weight to try and improve the prediction equation, where:

$$Wt = B_0 + B_1M_1 + B_2M_2 + \ldots + B_kM_k + e$$

where: B_o = Intercept
$B_1 \ldots B_k$ are regression coefficients for traits $M_1 \ldots M_k$
e = error

The final regression model was chosen by using step-up (forward) selection of variables (Snedecor and Cochran, 1989). Each regression of Wt on $M_1 \ldots M_k$ is calculated singly. The M value which gives the smallest residual mean square is selected, provided the F value is greater than 4. Then all k - 1 bivariate regressions in which M_1 appears are worked out. The variable which gives the greatest additional reduction in sums of squares after fitting M_1 is selected, provided its F exceeds 4. Call the second variable M_2. All trivariate regressions including both M_1 and M_2 are then computed, and again the variable that makes the greatest additional reduction in sums of squares is selected. The process stops when no M_i not yet selected gives an F value exceeding the boundary. The F to remove was chosen at 3.

The correlations (*r*) between each set of two variables was also calculated to measure the closeness of the linear relationship between two variables :

$$r = \Sigma x_1 x_2 / \sqrt{(\Sigma x_1^2)(\Sigma x_2^2)}$$

where: r = correlation coefficient
x_1 and x_2 are deviations of the two variables being correlated from their means

Principal component analyses were then used to investigate further the relationships between the variables. This involves rotating the axes on which the variables are displayed to minimise the total sum of squares (Webster, 1977). A second axis is then chosen at right angles to the first to minimise the sum of squares of the perpendicular distances from the points to it; the third and subsequent axes all perpendicular to one another are chosen similarly. This was done using variables standardised by the standard deviation. This is to ensure that the orientation of the axes are not controlled by the measures with the largest variance. The new functions derived in this way (principal components) are uncorrelated linear functions of the original variables and are independent if the original variables are normally distributed (Jolliffe, 1986).

7.3 Results

7.3.1 Linear Body Measurements and Weight

The means, standard deviations and coefficients of variation for each measurement recorded on the 39 animals are given in Table 7.1.

Table 7.1. Mean (μ), Standard Deviations (σ) and Coefficients of Variation (cv) for Body Measurements.

	μ	σ	*cv*
Length (cm)	56.54	3.62	6.40
Width Shoulder (cm)	9.18	1.94	21.13
Width Haunch (cm)	15.70	1.98	12.61
Height Front (cm)	100.37	6.43	6.41
Height Back (cm)	104.70	8.26	7.89
Heart Girth (cm)	112.82	5.72	4.85
Girth Back (cm)	123.08	5.89	4.79
Weight (kg)	97.46	8.91	9.14

The lowest *cvs* were found for girth measurements, the highest for measurements of widths.

Simple Regression

The 'best' equations for predicting liveweight from individual body measures are given in Table 7.2. The highest R^2 value was achieved using GF (0.60), with the lowest using HBL (0.17). Both the intercept and the gradient were significant for all body measures except WH. Figures 7.2 - 7.8 show graphs of individual body measures with weight and actual versus predicted weights.

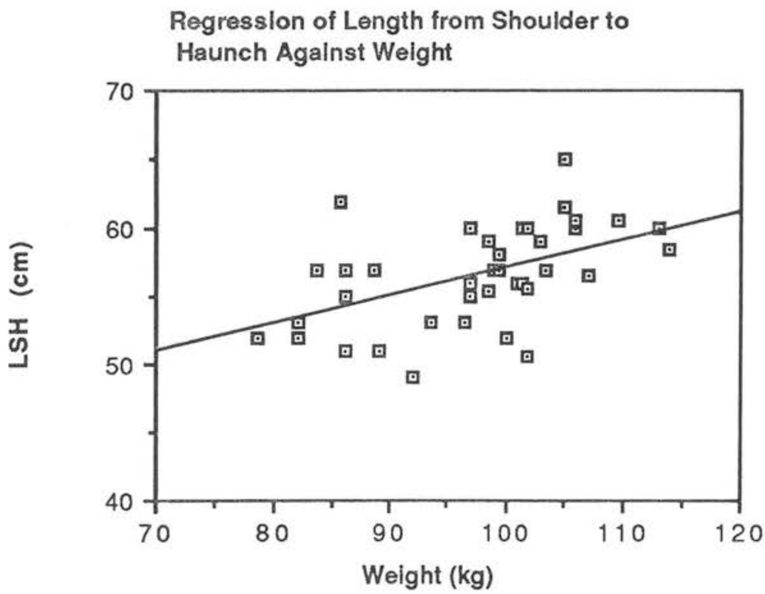
Table 7.2. Regression of Linear Body Measurements (cm) against live weight (kg) for red deer.

	Intercept (c)	Gradient (b)	Standard Error of gradient	R^2
LSH[1]	34.34^{***}	0.21^{***}	0.06	0.26
HFL	64.41^{***}	0.37^{***}	0.10	0.26
HBL	67.10^{***}	0.39^{**}	0.14	0.17
GF	69.51^{***}	0.50^{***}	0.07	0.60
GB	90.59^{***}	0.33^{***}	0.09	0.25
WS	-5.95^{*}	0.16^{***}	0.03	0.51
WH	2.74^{ns}	0.13^{***}	0.03	0.36

[1]LSH = Length, HFL = height front leg, HBL = height back leg, GF = heart girth, GB = girth at back, WS = width of shoulders, WH = width of haunch
(*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; ns not significant)

Plots of residuals of the regression analysis between the body measurements and body weight, the cube of the measurement or the log of the measurement were examined to find any trend to nonlinearity and to suggest the most appropriate predictor. Both the estimates from the cubic and logarithmic measures were found not to be significantly different from the estimates using linear measurement.

Figure 7.2 Graphs from the Regression Analysis of Length of Animal from Shoulder to Haunch (LSH) Against Body Weight for Stag Calves



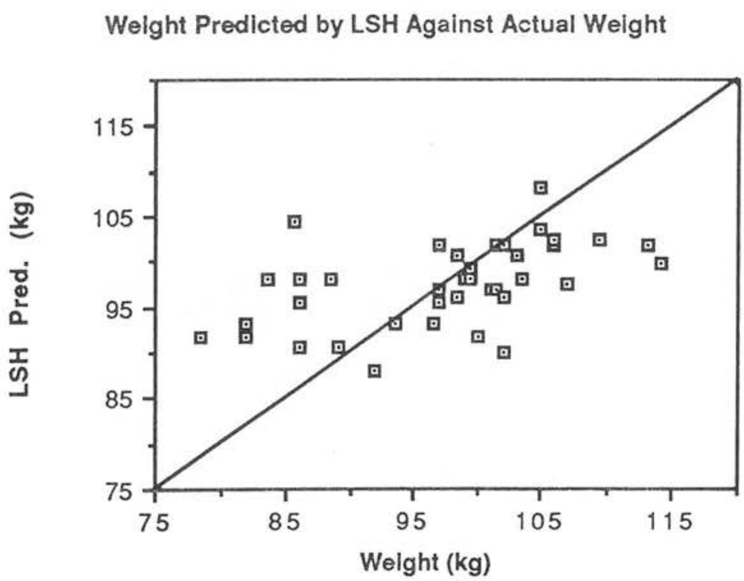
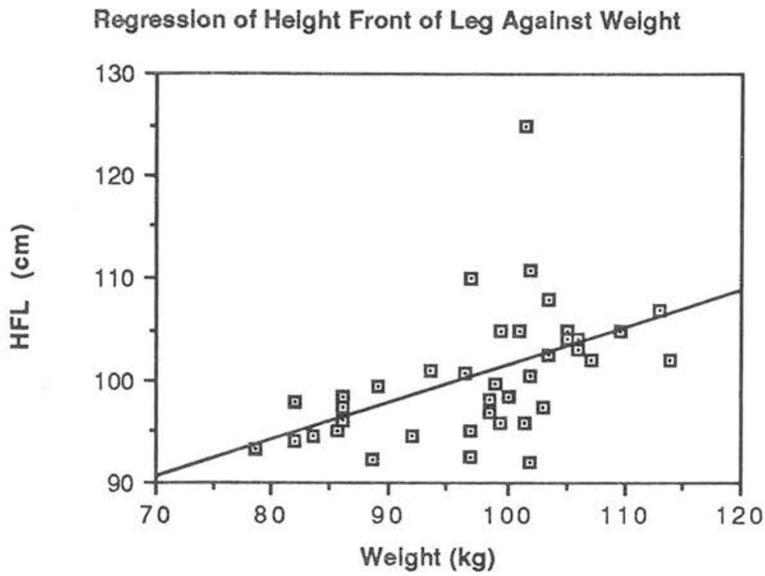


Figure 7.3 Graphs from the Regression Analysis of Height of Animal at Front Leg (HFL) Against Body Weight for Stag Calves



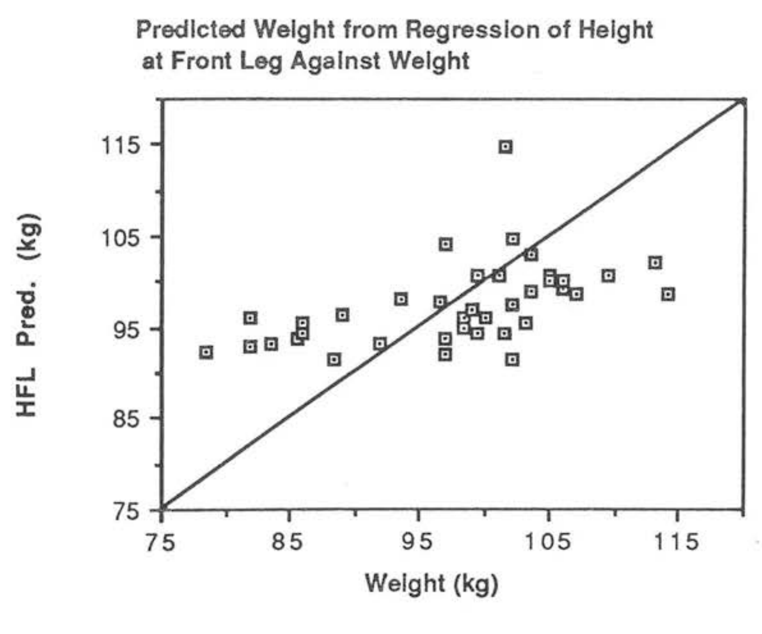
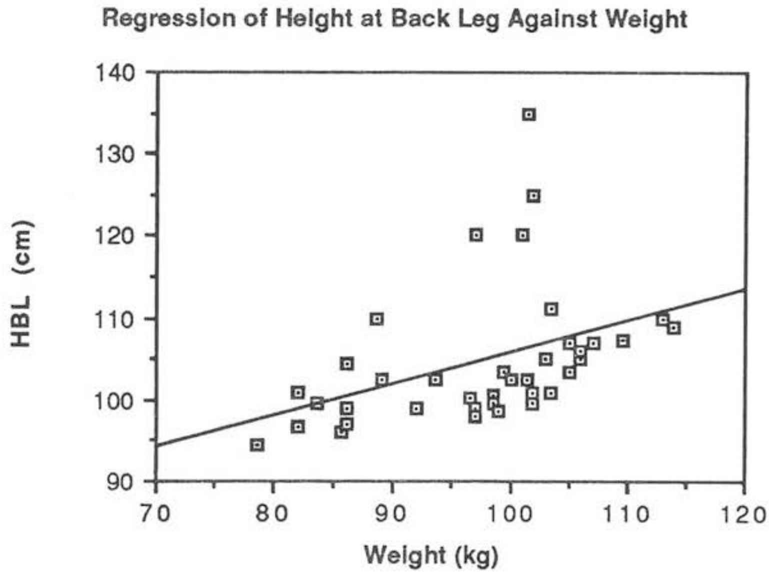


Figure 7.4 Graphs from the Regression Analysis of Height of Animal at Back Leg (HBL) Against Body Weight for Stag Calves



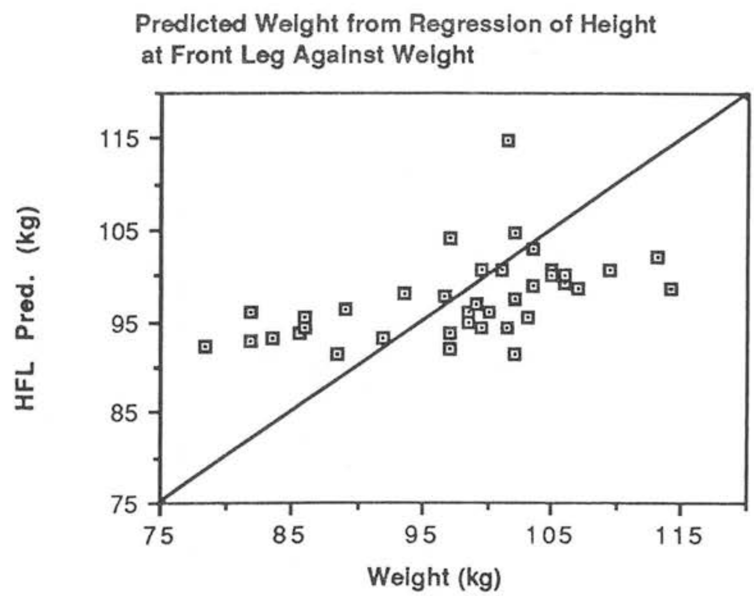
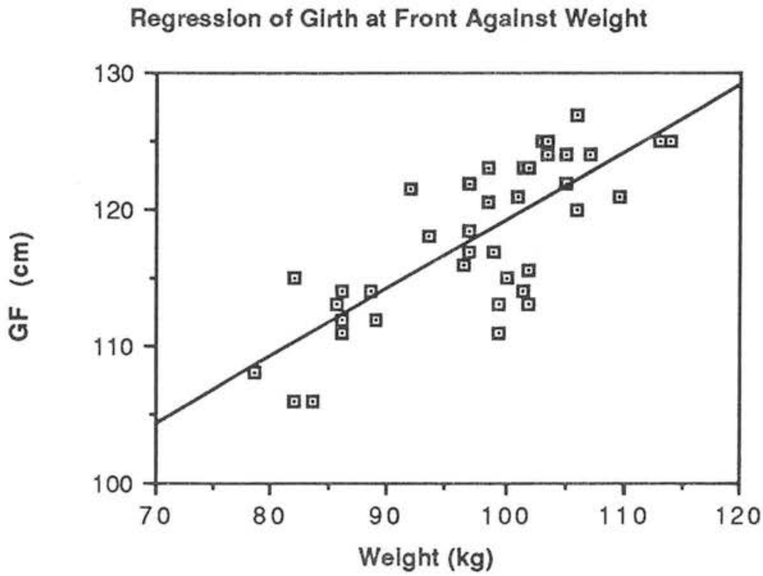


Figure 7.5 Graphs From the Regression Analysis of Girth at Front (Heart Girth; GF) Against Body Weight for Stag Calves



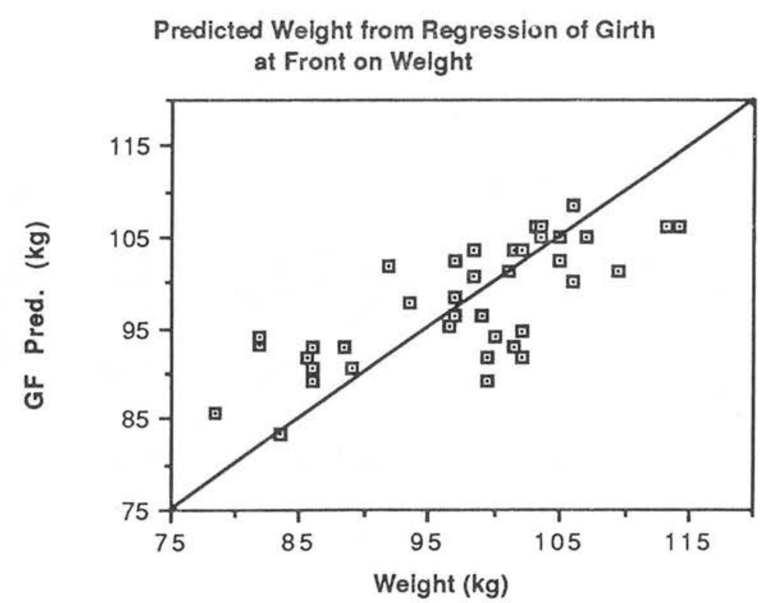
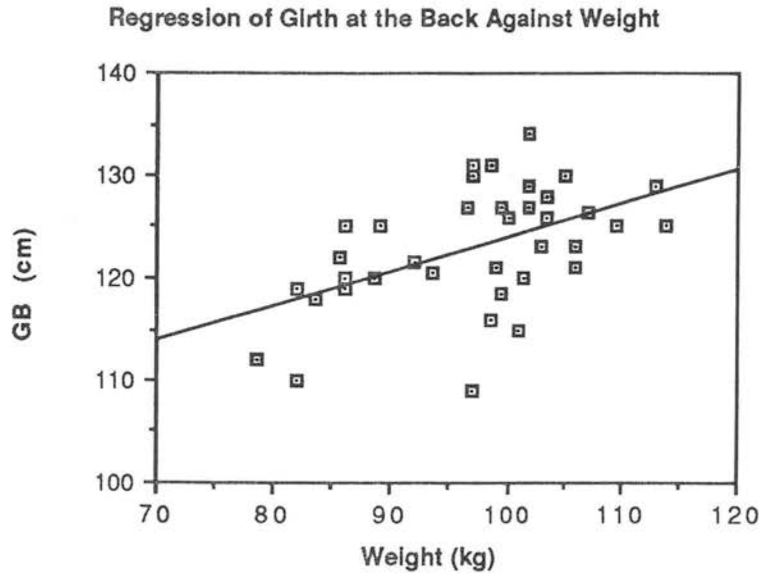


Figure 7.6 Graphs from the Regression Analysis of Girth at Back (Abdominal Girth; GB) Against Body Weight for Stag Calves



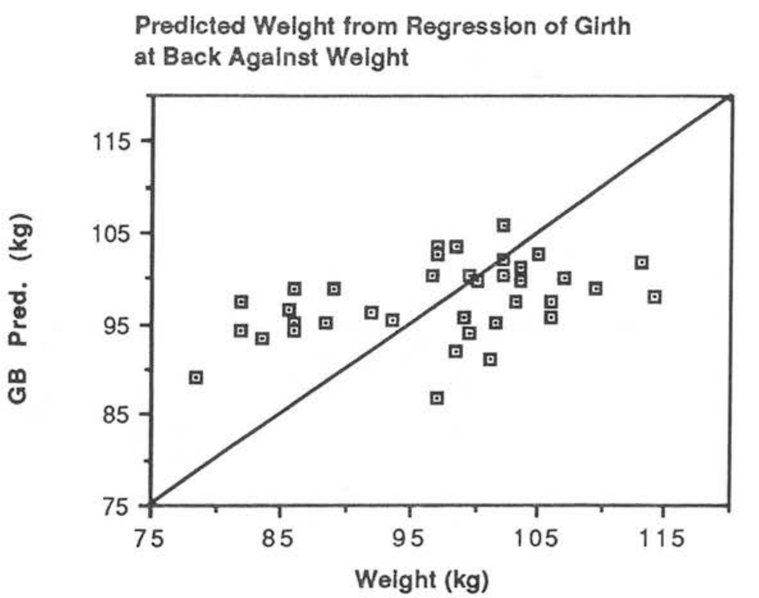
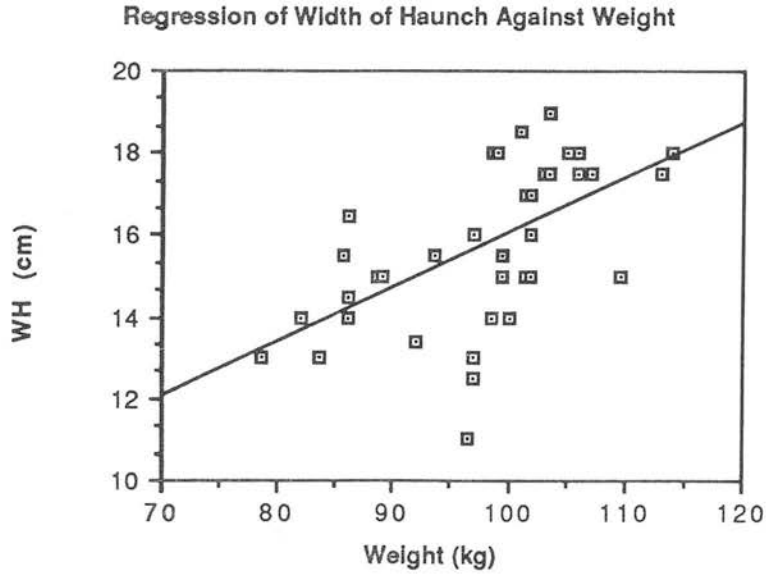


Figure 7.7 Graphs from the Regression Analysis of Width of Haunch (WH) Against Body Weight for Stag Calves



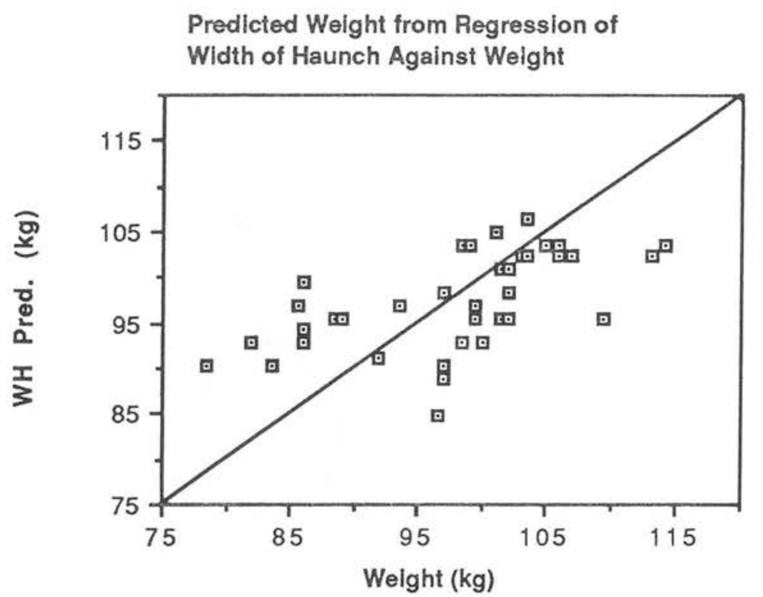
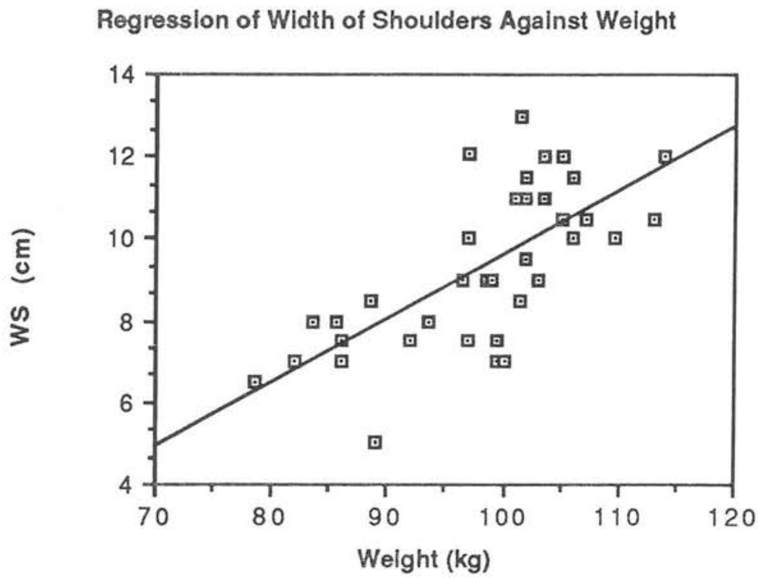
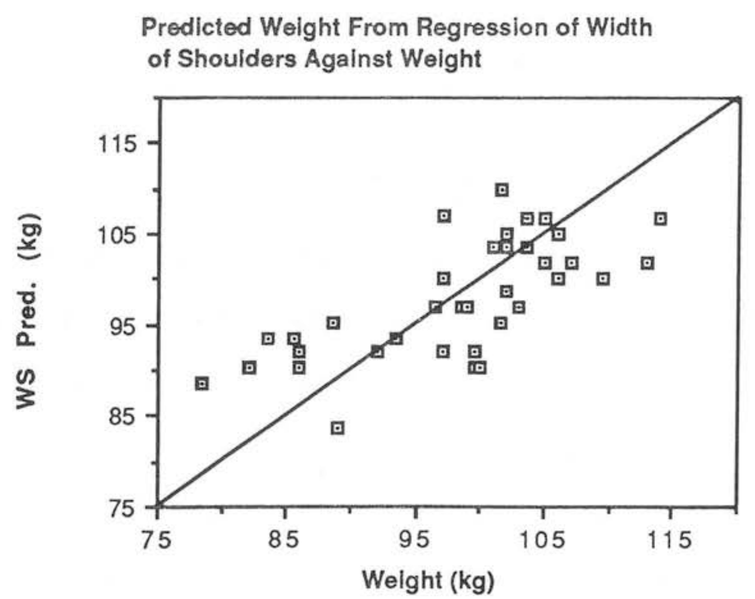


Figure 7.8 Graphs from the Regression Analysis of Width of Shoulders (WS) Against Body Weight for Stag Calves





Stepwise Linear Regression

Using regression techniques 'best' equations were derived for predicting liveweight from other variable measures. In practice only one or two predictor variables are desirable but these gave low R^2 values. The final model selected is shown below (Table 7.3):

Table 7.3. Multiple Regression Model for Prediction of Liveweight of Red Deer Using Linear Body Measures

	Coeffic	s.e.	t
Constant	-104.96	21.67	4.84
LSH[1]	0.66	0.23	2.85
HFL	0.32	0.14	2.29
GF	0.71	0.18	3.90
GB	0.40	0.15	2.72

[1]LSH = Length, HFL = height front leg, GF = heart girth, GB = girth at back

R^2 = 0.74 (R^2 adjusted for mean = 0.709)

A graph of actual versus predicted weight using the model in Table 7.3 above is given in Figure 7.9.

Correlations

Table 7.4 shows the correlations of each of the linear measures with each other and with weight and the corresponding probabilities associated with these correlations. LSH and GB tended to have non-significant correlations with other traits. GF has the highest correlation with weight (0.772) and height at the back the lowest (0.416). This is in agreement with results from the simple linear regressions. Between the linear measurements the highest correlation is between GF and WS (0.727) and the lowest between GB and HFL (0.048).

Figure 7.9 Predicted Weight vs Actual Weight using Multivariate Model with Linear Body Measurements

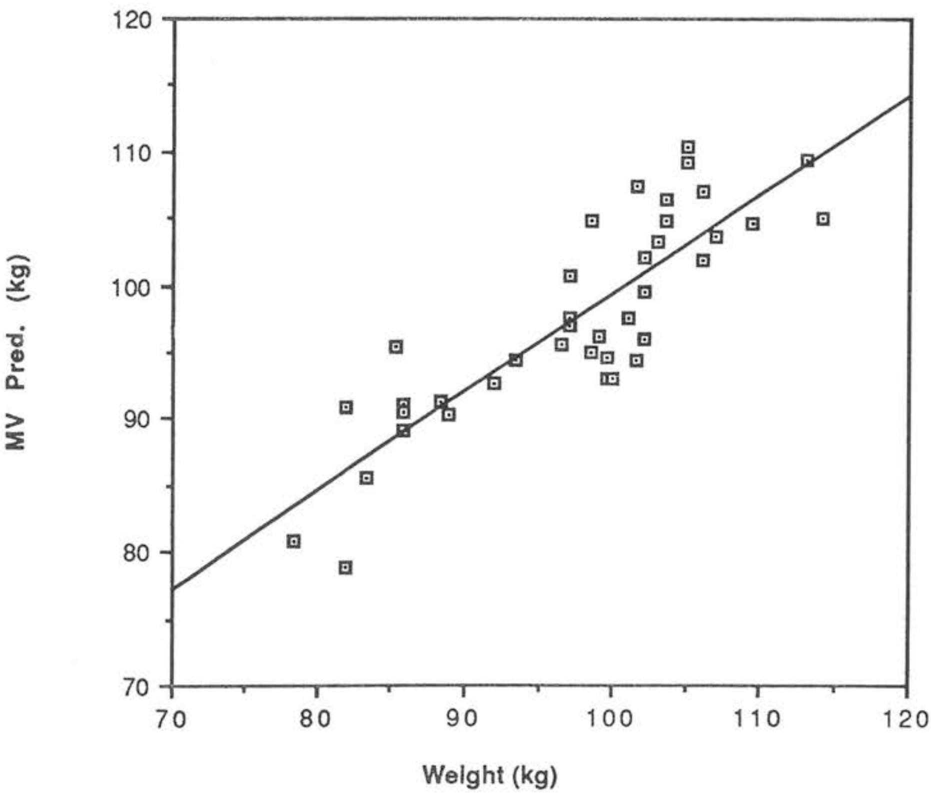


Table 7.4. Correlations between body measurements and weight taken on live stags at 16 months of age.

	LSH[1]	WS	WH	HFL	HBL	GF	GB	WT
LSH	-	0.544	0.460	0.179	0.021	0.359	0.142	0.510
WS		-	0.556	0.599	0.497	0.727	0.228	0.713
WH			-	0.386	0.440	0.650	0.344	0.598
HFL				-	0.664	0.480	0.048	0.511
HBL					-	0.396	0.237	0.416
GF						-	0.416	0.772
GB							-	0.505

[1]LSH = Length, HFL = height front leg, HBL = height back leg, GF = heart girth, GB = girth at back, WS = width of shoulders, WH = width of haunch, WT = weight

Principal Components

Table 7.5 shows principal components (PCs) for weight and body measures of stags. Over 68% of the variation is accounted for by the first two components. The first principal component shows coefficients which are very similar for each of the body measures and accounted for 53% of the total variation. This is what can be expected since all the correlations between the 8 variables are positive.

The larger a principal component the greater its discriminatory value. The magnitude of the coefficients within a given component are used to determine the relative importance of a measurement in describing that principal component (Carpenter *et al.*, 1971). The first principal component can be interpreted as a measure of general size. Similar results have been found by other authors (Wright, 1932; Jolicoeur and Mosimann, 1960; Carpenter *et al.*, 1971; Brown *et al.*, 1973; Arthur and Ahunu, 1989). The animals with a large value for the first principal component will be large framed and heavy. Similar values for the first principal component do not mean that animals are of equal dimensions. The first principal component infers that individuals with large values for one measure tend to have large values for the other measures.

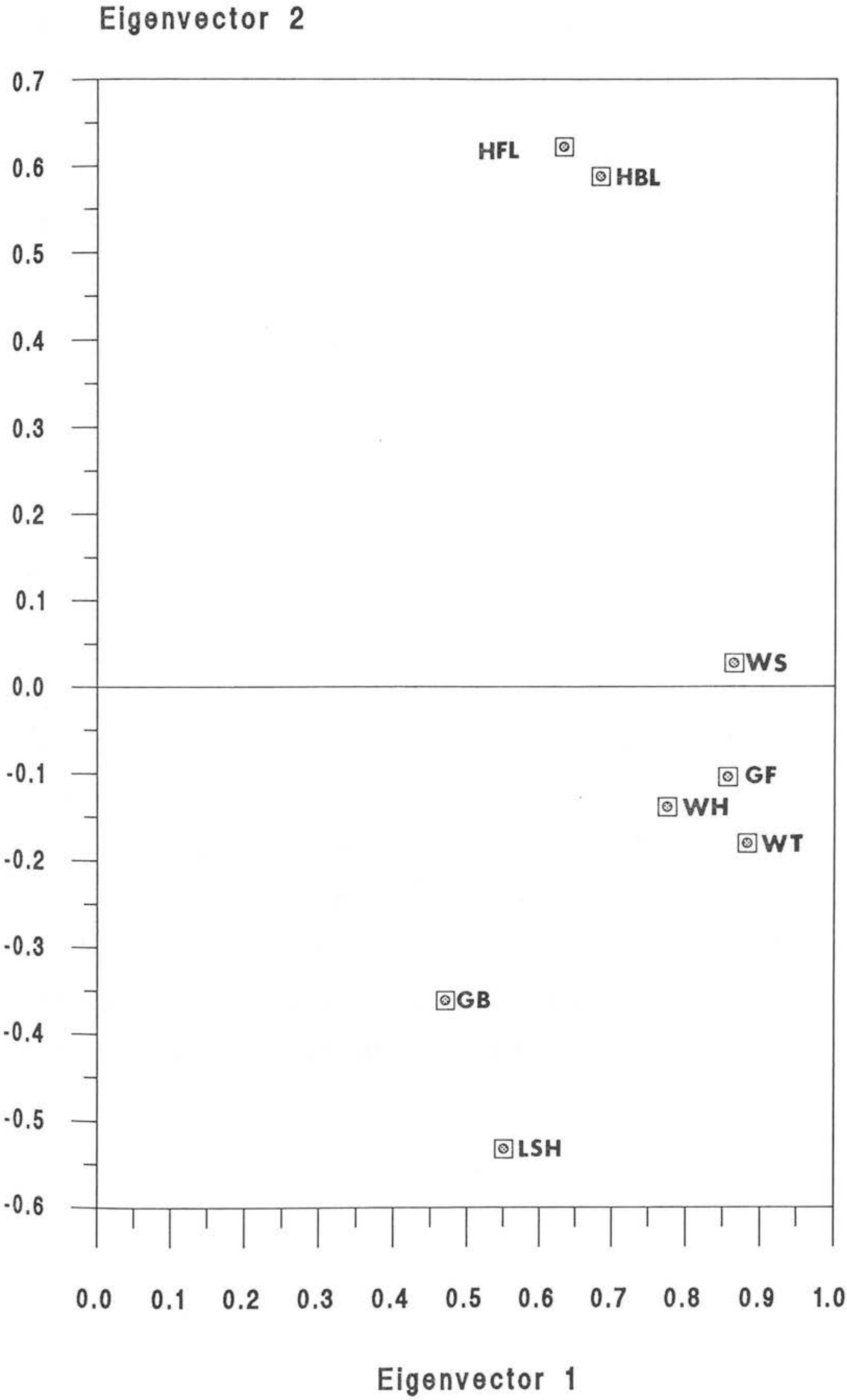
Table 7.5. Coefficients of Principal Components Obtained From Weight and Body Measures of Stags.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
WS[1]	0.419	0.027	0.259	-0.265	-0.017	0.589	-0.338	0.474
WH	0.376	-0.126	-0.005	0.799	-0.288	-0.188	-0.105	0.273
HFL	0.331	0.534	0.169	-0.206	0.135	-0.615	-0.369	-0.026
HBL	0.306	0.566	-0.202	0.297	0.355	0.390	0.331	-0.262
GF	0.415	-0.095	-0.087	-0.203	-0.613	0.106	-0.048	-0.617
GB	0.228	-0.329	-0.758	-0.094	0.360	-0.050	-0.352	0.003
LSH	0.267	-0.484	0.524	0.107	0.517	-0.036	-0.002	-0.374
WT	0.428	-0.164	-0.075	-0.314	-0.007	-0.268	0.078	0.334
%var	53.15	15.11	12.20	6.25	5.66	3.48	2.41	1.75

[1]LSH = Length, HFL = height front leg, HBL = height back leg, GF = heart girth, GB = girth at back, WS = width of shoulders, WH = width of haunch, WT = weight

The later PCs contrast some measurements with others and can be though of as defining certain aspects of shape. Animals with a high value for principal component 2 tend to be tall and have short body, narrow girth and are light. This implies that, one overall size has been accounted for, two fundamental contrasts exist in stags at this age; large versus small and short statured, wide animals versus tall and narrow individuals. The other components can be interpreted in a similar manner. These components can be useful in 'type' characterisation (Brown *et al.*, 1973). The eigenvalues are rescaled as the number of measures * proportion of variation explained by that component. Component weights are then multiplied by the square root of the corresponding eigenvalue to reflect the relative contribution of

Figure 7.10 Graphical Representation of The First Two Eigenvectors for Traits Measured on The Live Animal



the eigenvector in describing the correlation structure of the traits. Figure 7.10 shows a plot of the first two eigenvectors. This demonstrates the relationships between the traits as well as summarising the information in the principal component analysis. Heights and widths were closely related to each other; more so than girths. From Figure 7.10 it can be seen that widths and girth at the front were most closely related to weight.

7.3.2 Carcass Traits

Full carcass dissection was available on 19 of the stags. After slaughter the carcasses were halved and measurements taken on one half of the carcass. Figures given on part carcass traits refer to one half of the carcass only. Table 7.6 shows means, standard deviations and coefficients of variation for carcass traits. Traits associated with fat show the highest degree of variation while weight traits have the lowest. (The names of the traits have been shortened. In all cases SC is subcutaneous fat; IMF is intramuscular fat; TOT is total ; LA is lumbar abdominal ; HL is hind leg ; FL is frontleg ; S_BP is side before preparation; FQ_AP is forequarter after preparation and similarly for hindquarter (HQ_AP) ; TISS = tissue).

Table 7.6. Means(μ), Standard Deviations (σ) and Coefficients of Variation (cv) for Traits Measured on the Carcass.

	μ	σ	cv
Liveweight (kg)	96.86	6.48	0.07
Hot carcass (kg)	59.52	3.73	0.06
S_BP (kg)	28.36	1.70	0.06
FQ_AP (kg)	14.84	0.87	0.06
HQ_AP (kg)	12.93	0.87	0.07
FL (g)	4207.00	150.21	0.04
LA (g)	2939.26	279.77	0.10
HL (g)	9999.00	629.03	0.06
SC_FL (g)	24.00	12.05	0.50
IMF_FL (g)	104.00	24.07	0.23
SC_LA (g)	199.32	65.51	0.33
IMF_LA (g)	151.58	36.63	0.24
SC_HL (g)	221.78	54.95	0.25
IMF_HL (g)	256.26	46.14	0.18
LEAN_FL (g)	3025.26	108.35	0.04
LEAN_LA (g)	2312.58	192.39	0.08
LEAN_HL (g)	7791.21	470.49	0.06
BONE_FL (g)	876.16	51.03	0.06
BONE_LA (g)	180.68	34.15	0.19
BONE_HL (g)	1355.10	68.88	0.05
TOT_LEAN (g)	20659.00	1091.83	0.05
TOT_BONE (g)	3854.10	213.82	0.06
TOT_SC (g)	613.05	149.42	0.24
TOT_IMF (g)	1481.79	325.67	0.22
TOT_TISS (g)	27403.52	1574.93	0.06
%LEAN	75.40	1.18	0.02
%BONE	14.07	0.69	0.05
%SC	2.23	0.50	0.22
%IMF	8.28	0.95	0.12

S_BP is side before preparation; FQ = fore quarter; HQ = hind quarter; AP = after preparation; FL= front leg; LA = lumbar abdominal; HL = hind leg; SC = subcutaneous fat; IMF = intramuscular fat; tot = total; TISS = tissue

Stepwise Linear Regression

The body measures was used to predict the important carcass traits. Table 7.7 shows the 'best' results for prediction of carcass components from linear measurements using both multiplicative and simple regression techniques.

The best predictive equations for traits measured on the carcass were those associated with the foreleg and measurements of bone. The worst measures were those associated with fat. The length of the animal (LSH), front girth (GF) and haunch width (WH) are the traits which appear most frequently in the equations.

Table 7.7. Prediction of Carcass Components using Linear Body Measures.

Trait		Coeff.	s.e.	t value	R^2
S_BP					
	Const.	8947.62	5060.09	1.77	0.48
	LSH	255.94	97.37	2.63	
	WH	297.99	143.10	2.08	
FQ_AP					
	Const.	-7948.05	4357.70	-1.82	0.65
	HFL	40.99	16.73	2.45	
	LSH	208.95	38.46	5.43	
	GB	53.95	20.78	2.60	
HQ_AP					
	Const.	5088.24	2811.06	1.81	0.39
	LSH	82.37	54.09	1.52	
	WH	193.51	79.50	2.43	
FL					
	Const.	1354.69	699.13	1.94	0.57
	LSH	18.61	8.21	2.27	
	WH	24.47	12.29	1.99	
	GB	11.22	4.03	2.79	
LA					
	Const.	613.83	111.19	0.61	0.24
	LSH	27.79	19.46	1.43	
	WH	45.67	28.60	1.60	
HL					
	Const.	4690.05	2847.76	1.66	0.39
	LSH	49.69	8.39	2.93	
	WH	151.99	27.69	5.19	
TOT_SC					
	Const.	-816.46	535.06	1.53	0.26
	LSH	25.17	9.41	2.68	
TOT_IMF					
	Const.	-1431.44	1196.65	-1.19	0.22
	LSH	51.30	21.04	2.24	
%LEAN					
	Const.	60.42	4.60	13.13	0.52
	LSH	0.18	0.07	2.59	
	WH	-0.38	0.11	-3.51	
	HBL	0.10	0.02	4.56	
%BONE					
	Const.	21.23	2.11	10.05	0.46
	LSH	-0.17	0.04	-4.07	
	WH	0.14	0.06	2.28	
%SC					
	Const.	2.55	3.51	0.73	0.23
	LSH	0.09	0.03	2.58	
	GF	-0.04	0.03	-1.48	

(Table 7.7 Contd over)

(Table 7.7 contd)

Trait		Coeff.	S.E.	t val	R^2
%IMF					
	Const.	0.32	3.41	0.09	0.26
	LSH	0.09	0.07	1.41	
	WH	0.16	0.10	1.70	
LEAN_FL					
	Const.	-295.72	680.21	-0.43	0.57
	LSH	16.63	5.46	3.04	
	GB	8.72	2.73	3.20	
	GF	10.62	4.69	2.27	
LEAN_LA					
	Const.	-1947.68	1104.23	-1.76	0.48
	LSH	30.58	10.52	2.91	
	GF	20.74	9.13	2.27	
LEAN_HL					
	Const.	5700.58	687.12	8.30	0.32
	WH	127.76	41.64	3.07	
BONE_FL					
	Const.	-170.07	244.14	-0.70	0.49
	HFL	3.54	1.19	2.98	
	GB	5.49	1.46	3.77	
BONE_LA					
	Const.	67.22	55.63	1.21	0.15
	WH	6.93	3.37	2.06	
BONE_HL					
	Const.	1387.09	200.41	6.92	0.51
	LSH	-7.97	3.86	-2.07	
	WH	25.69	5.67	4.53	
TOT_LEAN					
	Const.	-1217.95	6319.01	-0.19	0.47
	LSH	199.05	60.17	3.31	
	GF	86.90	52.26	1.66	
TOT_BONE					
	Const.	350.11	808.08	0.43	0.68
	WH	56.33	13.94	4.04	
	HFL	12.50	4.05	3.09	
	GB	10.44	5.04	2.07	
TOT_TISS					
	Const.	8715.83	4486.78	1.94	0.53
	LSH	246.33	86.34	2.85	
	WH	287.25	126.89	2.26	

S_BP is side before preparation; FQ = fore quarter; HQ = hind quarter; AP = after preparation; FL= front leg; LA = lumbar abdominal; HL = hind leg; SC = subcutaneous fat; IMF = intramuscular fat; tot = total; TISS = tissue

Correlations

Table 7.8 shows some of the correlations between carcass traits. The correlations between liveweight and other weights are generally high. The weight of HL is highly correlated with TOT_LEAN (0.842) but negatively correlated with % Lean (_0.506). Correlations between other traits and FL tend to be lower than with HL but higher for TOT_BONE.

The lowest correlations tend to be those with bone and subcutaneous fat traits. Intramuscular fat (total and %) are highly correlated with several of the weight traits both for individual body parts and total weights. The correlations of percentage lean and percentage bone with all other traits are negative. The relationship between subcutaneous fat and the other carcass traits is less well defined, but correlations tend to be low to moderate for most traits. Intramuscular fat traits tend to have higher correlations with other traits.

Table 7.8. Correlations between Carcass Traits

	HOTC	S_BP	FQ_AP	HQ_AP	TOTL	TOTB	TOTS	TOTI	TOTT	%LEAN	%BONE	%SC	%IMF
LIVE	0.762	0.706	0.674	0.656	0.678	0.497	0.366	0.704	0.731	-.406	-.291	0.250	0.592
HOTC		0.966	0.875	0.943	0.919	0.622	0.534	0.791	0.965	-.451	-.424	0.375	0.684
S_BP			0.935	0.939	0.946	0.642	0.578	0.791	0.992	-.465	-.432	0.422	0.687
FQ_AP				0.764	0.926	0.567	0.473	0.717	0.942	-.352	-.465	0.329	0.623
HQ_AP					0.872	0.649	0.550	0.732	0.926	-.464	-.339	0.392	0.623
TOTL						0.509	0.448	0.617	0.967	-.175	-.554	0.311	0.479
TOTB							0.110	0.493	0.631	-.616	-.401	-.014	0.492
TOTS								0.489	0.558	-.470	-.542	0.980	0.464
TOTI									0.762	-.742	-.333	0.388	0.956
TOTT										-.419	-.456	0.397	0.660
%LEAN											-.201	-.447	-.847
%BONE												-.497	-.222
%IMF													0.390
FL	0.774	0.812	0.797	0.764	0.763	0.710	0.262	0.591	0.809	-.404	-.140	0.119	0.559
LA	0.798	0.806	0.652	0.859	0.780	0.502	0.530	0.620	0.812	-.360	-.382	0.384	0.525
HL	0.937	0.924	0.756	0.981	0.842	0.665	0.530	0.749	0.911	-.506	-.301	0.378	0.661

Principal Component Analysis for Carcass Traits

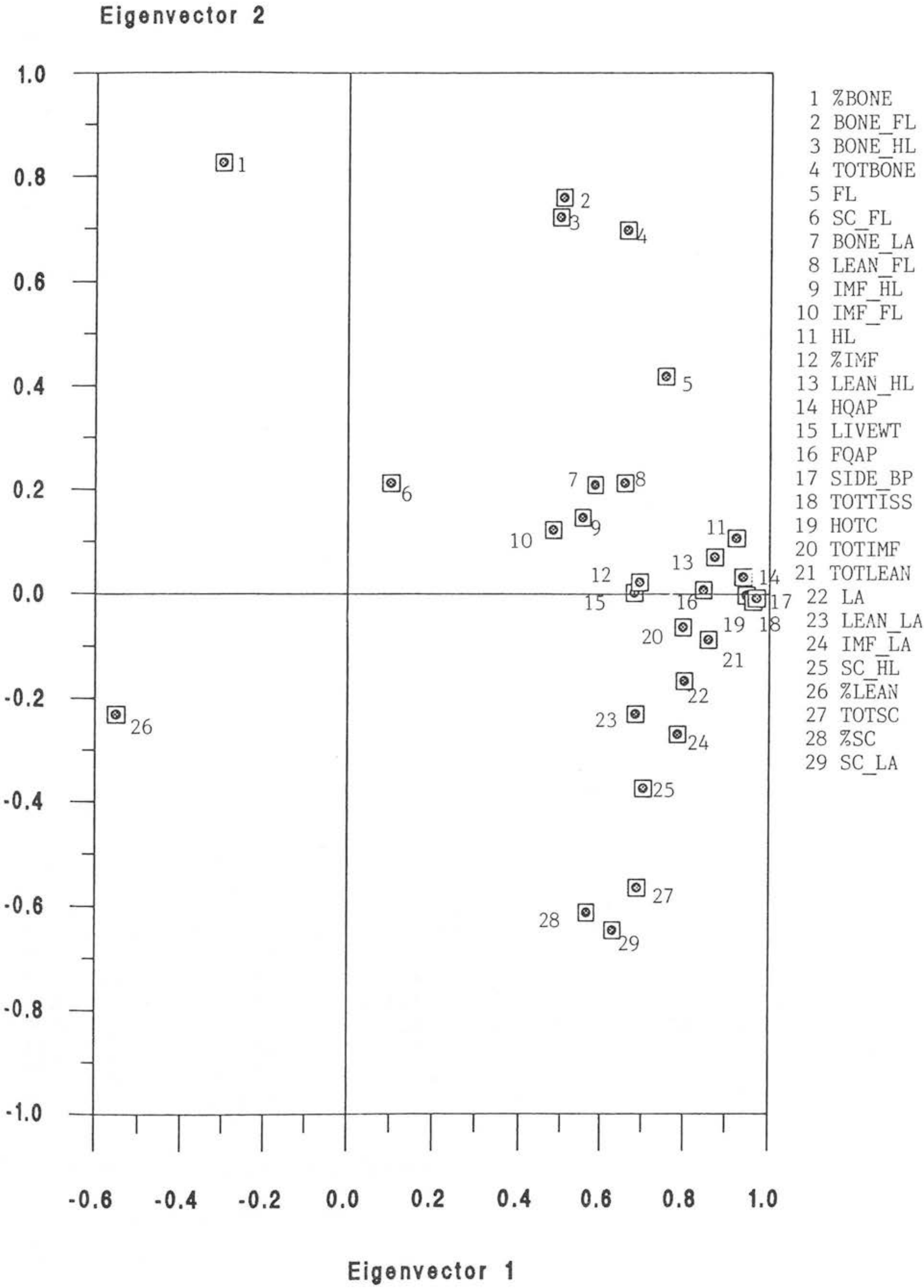
Table 7.9. Principal Components for Carcass Traits on Stag Calves

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
LIVEWT	0.176	0.001	0.008	0.087	-0.232	0.486	0.196	0.472
HOT_CAR	0.245	-0.001	-0.101	-0.018	-0.127	-0.029	0.163	0.109
S_BP	0.251	-0.004	-0.102	-0.054	0.036	0.026	0.054	-0.070
FQ_AP	0.219	0.004	-0.136	-0.225	0.050	0.203	0.039	-0.088
HQ_AP	0.243	0.016	-0.108	0.130	-0.009	-0.166	0.033	-0.009
FL	0.195	0.207	-0.155	-0.200	0.060	-0.053	-0.311	0.242
LA	0.207	-0.082	-0.078	0.279	-0.133	0.004	-0.163	-0.373
HL	0.239	0.053	-0.080	0.051	0.027	-0.214	0.179	0.106
SC_FL	0.026	0.105	-0.092	-0.287	0.635	0.080	0.109	-0.245
IMF_FL	0.124	0.060	0.124	0.088	0.413	0.543	-0.041	0.000
SC_LA	0.163	-0.319	0.071	0.130	0.086	-0.153	-0.056	0.005
IMF_LA	0.203	-0.133	0.236	0.034	-0.234	0.070	-0.022	-0.158
SC_HL	0.182	-0.185	0.182	0.080	0.189	-0.193	0.223	-0.159
IMF_HL	0.143	0.072	0.166	-0.459	-0.205	-0.131	-0.076	-0.093
LEAN_FL	0.170	0.105	-0.247	-0.181	0.043	-0.158	-0.561	0.098
LEAN_LA	0.177	-0.099	-0.252	0.226	-0.105	0.199	-0.039	-0.278
LEAN_HL	0.226	0.035	-0.185	0.045	-0.005	-0.212	0.168	0.107
BONE_FL	0.130	0.376	0.094	-0.047	-0.055	-0.014	0.136	0.276
BONE_LA	0.151	0.103	0.110	0.440	0.104	0.053	-0.487	0.089
BONE_HL	0.128	0.357	0.041	0.203	0.038	-0.261	0.242	-0.091
TOT_LEAN	0.222	-0.043	-0.272	-0.055	-0.008	0.081	0.105	-0.057
TOT_BONE	0.171	0.345	0.058	0.121	0.045	0.020	0.078	-0.119
TOT_SC	0.178	-0.279	0.156	0.031	0.221	-0.131	-0.003	0.265
TOT_IMF	0.206	-0.031	0.251	-0.177	-0.146	0.154	0.000	-0.120
TOT_TISS	0.249	-0.007	-0.132	-0.055	0.001	0.061	0.079	-0.060
%LEAN	-0.143	-0.114	-0.459	0.029	-0.030	0.047	0.081	0.037
%BONE	-0.078	0.408	0.202	0.212	0.062	-0.046	0.012	-0.049
%SUB	0.146	-0.302	0.211	0.012	0.247	-0.139	-0.010	0.301
%IMF	0.179	0.011	0.329	-0.232	-0.152	0.065	-0.108	-0.182
%VAR	51.47	14.12	10.20	6.76	5.43	4.28	2.19	1.48

S_BP is side before preparation; FQ = fore quarter; HQ = hind quarter; AP = after preparation; FL= front leg; LA = lumbar abdominal; HL = hind leg; SC = subcutaneous fat; IMF = intramuscular fat; tot = total; TISS = tissue

Table 7.9 shows the first eight vectors of principal component weights for traits measured on the carcass. PC1 and PC2 account for 51% and 14% of the total variation respectively. The coefficients for PC1 are generally similar for all traits, but % lean and % bone have negative signs. This first component can then be thought of (as before) as a general measure of size. PC2 contrasts subcutaneous fat and bone traits.

Figure 7.11 Graphical Representation of The First Two Eigenvectors For Carcass Traits



The two dominant eigenvalues were 14.92 and 4.09 respectively. A graphical representation of the first two eigenvectors (Figure 7.11) demonstrates the relationship between the traits and summarises the information of the principal component analysis. Eigenvalues and eigenvectors are calculated as before. Figure shows how the traits are grouped into those related to total weights, bone and subcutaneous fat.

Photographic Data

Since many farmers and breeders choose animals for breeding on the basis of 'conformation' or a visual assessment of the relative proportion of different parts of the animal. Areas of fore, mid and hind portions of the animals as well as the relative proportions of these parts were analyzed to see if the relative proportion of the parts could be predicted from photographs. Table 7.10 gives a summary of these data.

Table 7.10. Summary of Area of Body Parts from Photographs

	Mean	Min	Max	S.D.	C.V.
Fore (cm^2)	1098.1	861.3	1430.0	173.0	0.16
Mid (cm^2)	1721.7	1214.5	2503.7	282.1	0.16
Hind (cm^2)	1469.2	1086.0	2002.0	269.3	0.18
Whole (cm^2)	4307.5	3328.0	5819.0	642.6	0.15
Wt (kg)	97.7	78.5	114.0	8.77	0.09
Fore/who	0.255	0.218	0.296	0.018	0.07
Mid/who	0.400	0.334	0.491	0.032	0.08
Hind/who	0.340	0.270	0.392	0.028	0.08
For/hin	0.754	0.635	0.929	0.079	0.10
Mid/hin	1.189	0.860	1.770	0.190	0.16
For/mid	0.644	0.444	0.830	0.084	0.13

Correlations of these different measures with each other and with their corresponding weights are given in Table 7.11. From this it can be seen that correlations with the mid-section were generally high, otherwise correlations between photo areas, ratios of photo areas and weights are poor to moderate (-0.50 to +0.46).

Table 7.11. Correlations of Ratios of Weights and Areas of Limbs and Body Parts (Lower Figures are Probabilities).

	FROM PHOTOS					FROM ACTUAL WEIGHTS					
	M/W	H/W	F/H	M/H	F/M	F/W	M/W	H/W	F/H	M/H	F/M
F/W	-0.21	-0.18	0.66	0.02	0.69	-0.50	0.42	-0.44	-0.08	-0.10	0.04
M/W		-0.82	0.53	0.95	-0.85	-0.40	0.27	-0.19	0.33	0.52	0.55
H/W			-0.85	-0.95	0.51	0.64	0.03	0.37	0.45	-0.30	-0.45
F/H				0.74	-0.04	-0.72	-0.22	-0.49	-0.37	0.20	-0.33
M/H					-0.69	-0.54	0.13	-0.30	-0.39	0.46	-0.53
F/M						0.02	-0.42	-0.11	0.20	-0.43	0.43
F/W							0.34	0.78	0.36	-0.32	0.43
M/W								-0.64	-0.42	0.66	-0.70
H/W									-0.30	-0.15	-0.02
F/H										-0.24	0.68
M/H											-0.87

(F = fore leg ; M = mid section (lumbar abdominal region) ; H = hind leg ; W = Whole animal)

Table 7.12 shows the prediction of carcass weights from areas of body parts taken from photographs, using simple regression techniques. These were generally poor predictors with R^2 values ranging from 2 to 30%. The best predictors were generally those involved with the foreleg.

Table 7.12. Prediction Equations using Area Measures from Photographs.

Dep.	Ind.	Intercept	Grad.	R^2
Wt	Fore	81.81***	0.017*	0.31
	Hind	98.93***	0.00	0.21
	Mid	89.45***	0.003*	0.22
	Who	88.04***	0.003	0.16
S_BP	Fore	22298.6***	5.041*	0.22
	Hind	25087.6***	2.025	0.07
	Mid	24621.6***	2.082	0.15
	Who	23459.2***	1.058	0.15
FQAP	Fore	11722.3***	2.59*	0.22
	Hind	13073.1***	1.09	0.07
	Mid	13364.9***	0.82	0.09
	Who	12677.2***	0.46	0.11
HQAP	Fore	10142.3***	2.32	0.18
	Hind	11425.3***	0.93	0.06
	Mid	10872.1***	1.15	0.18
	Who	10375.5***	0.55	0.16
FL	Fore	3762.77***	0.37	0.15
	Mid	3810.75***	0.25	0.13
	Hind	3954.04***	0.14	0.09
	Who	3791.51***	0.09	0.14
LA	Fore	1965.89***	0.81*	0.21
	Hind	2430.60***	0.32	0.06
	Mid	2055.96***	0.49**	0.31
	Who	1992.89***	0.20*	0.21
HL	Fore	8223.58***	1.48	0.14
	Hind	9282.88***	0.44	0.02
	Mid	8755.60***	0.69	0.12
	Who	8476.53***	0.33	0.11
TOTLEAN	Fore	16405.4***	3.54*	0.26
	Hind	18052.6***	1.61	0.11
	Mid	18195.5***	1.37	0.16
	Who	17221.4***	0.74*	0.18
TOTTISS	Fore	21577.5***	4.84*	0.24
	Hind	24389.9***	1.86	0.07
	Mid	23814.8***	2.00	0.16
	Who	22748.4***	1.00	0.16

(*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; S_BP is side before preparation; FQ = fore quarter; HQ = hind quarter; AP = after preparation; FL= front leg; LA = lumbar abdominal; HL = hind leg)

Multiplicative models including only traits measured on the photographs did not improve prediction for these traits. Stepwise linear regression was then used including both profile and linear measurements. The results are given in Table 7.13.

Table 7.13. Prediction of Carcass Traits using Profile Areas and Linear Body Measurements.

Trait		Coeff.	s.e.	R^2
WT				
	Const.	17.89	28.23	0.56
	Fore	0.03	0.01	
	Hind	-0.01	0.00	
	GF	0.54	0.22	
S_BP				
	Const.	9764.82	5997.90	0.34
	Fore	4.51	2.04	
	LSH	231.94	101.04	
FQ_AP				
	Const.	4985.23	2793.32	0.47
	Fore	2.71	0.97	
	LSH	170.16	52.79	
	WS	-292.43	122.95	
HQ_AP				
	Const.	3902.42	3076.19	0.32
	Mid	1.07	0.54	
	LSH	125.17	52.41	
LA				
	Const.	115.18	925.78	0.41
	Mid	0.47	0.16	
	LSH	34.85	15.77	
TOT_LEAN				
	Const.	6149.23	3166.08	0.56
	Fore	3.49	1.09	
	LSH	233.30	59.83	
	WS	-279.69	139.36	
TOT_TISS				
	Const.	9044.63	5343.91	0.39
	Fore	4.32	1.84	
	LSH	231.92	90.02	
TOT_SC				
	Const.	1307.92	318.04	0.33
	Mid	0.18	0.09	
	HBL	-9.35	2.96	
LEAN_FL				
	Const.	1618.17	362.49	0.45
	Hind	0.23	0.08	
	LSH	18.31	5.87	
LEAN_LA				
	Const.	1434.79	8778.37	0.59
	Mid	0.23	0.09	
	LSH	31.36	9.06	
	GB	-10.55	4.76	
BONE_LA				
	Const.	74.08	39.82	0.26
	Mid	0.06	0.02	

(Other traits had no significant models which included a profile area; S_BP is side before preparation; FQ = fore quarter; HQ = hind quarter; AP = after preparation; FL= front leg; LA = lumbar abdominal; HL = hind leg; Sc = subcutaneous fat; TISS = tissue)

Models including linear body measurements with the profile areas improved the prediction of carcass traits. The best predictions were for LEAN_LA (R^2 = 0.59), WT (R^2 = 0.56) and TOT_LEAN (R^2 = 0.56).

Prediction of Carcass Measurements Using Liveweight

Prediction of carcass traits by using liveweight of animal alone was also investigated (Table 7.14). The predictive ability of these simple regression equations is generally high and in some cases higher than with other measures (Table 7.7). The worst prediction was of total subcutaneous fat (R^2 = 0.31) and the highest was the prediction of weight of the hind leg (R^2 = 0.71). Comparing Table 7.7 and Table 7.14 it is apparent that while the linear measurements allow good prediction of bone and forequarter weight is a good predictor of hindquarter and total carcass weights.

Table 7.13. Linear Regression of Weight on Carcass Measurements

Dependent	Ind.	Intercept	Gradient	R^2
TOT_TISS	Wt	898.68	258.40***	0.65
TOT_LEAN	Wt	3538.99	166.89***	0.57
TOT_SC	Wt	-396.57	9.84	0.11
TOT_IMF	Wt	-3494.45**	48.51***	0.54
TOT_BONE	Wt	1238.58	0.02**	0.35
HL	Wt	-1007.90	107.30***	0.71
LA	Wt	-1275.21	41.09***	0.52
FL	Wt	2220.92***	19.36**	0.40
HQ_AP	Wt	-2025.99	145.82***	0.69
FQ_AP	Wt	2584.08	119.43**	0.45
S_BP	Wt	436.00	272.19***	0.63
%LEAN	Wt	85.62***	-0.10	0.17
%BONE	Wt	17.88***	-0.04	0.07
%IMF	Wt	-4.17	0.12**	0.39
%SC	Wt	0.56	0.02	0.03

(*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$S_BP is side before preparation; FQ = fore quarter; HQ = hind quarter; AP = after preparation; FL= front leg; LA = lumbar abdominal; HL = hind leg; SC = subcutaneous fat; IMF = intramuscular fat)

7.3.3 Prediction of Birth Weight From Body Measures

Data was available on birth weights, girths and hind foot lengths on a total of 226 calves of both sexes. Table 7.15 shows a summary of this data. Males were heavier and had larger girths and hind foot lengths than females.

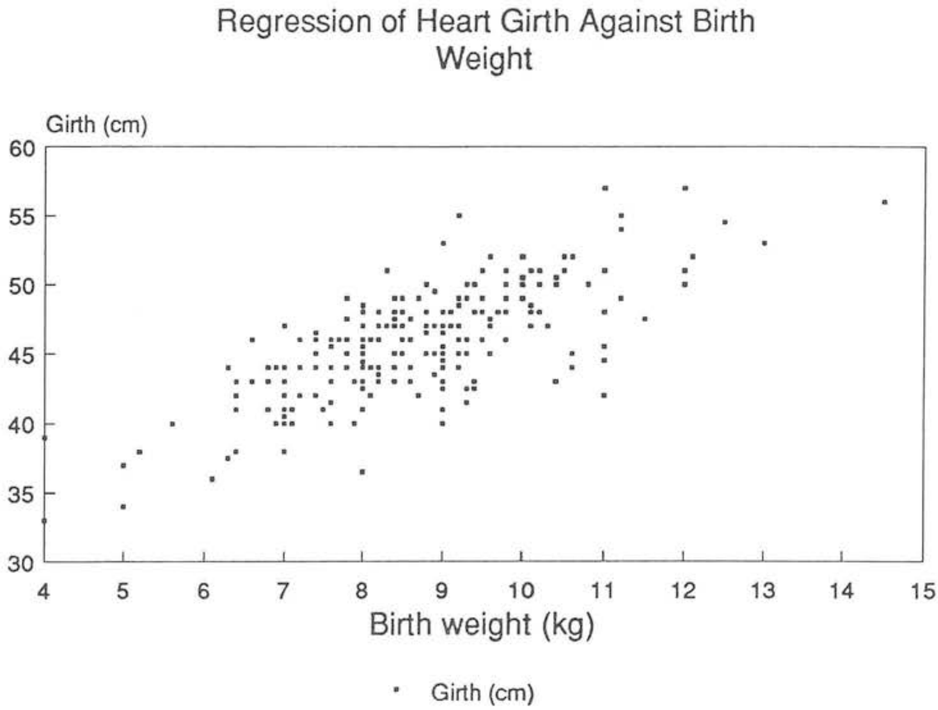
Table 15. Summary of Traits Measured on Red Deer at Birth.

	No		μ	σ	C.V.
All Animals	226	Birth Wt.	8.715	1.488	0.171
		Girth	45.924	3.938	0.086
		Foot Lgth.	25.310	1.397	0.055
Males	119	Birth Wt.	8.977	1.398	0.156
		Girth	46.176	3.597	0.078
		Foot Lgth.	25.580	1.276	0.050
Females	107	Birth Wt.	8.423	1.537	0.182
		Girth	45.644	4.285	0.094
		Foot Lgth.	25.009	1.470	0.059

Simple Regressions

The results from using simple regressions to predict weight of calves at birth is given in Table 7.16. Predictions are made for males and females separately and all animals together. In all cases the HFL was a better predictor of birth weight as measured by R^2. A graphical representation of this data is given in Figures 7.12 - 7.13.

Figure 7.12 Graphs From the Regression Analysis of Heart Girth at Birth Against Birth Weight



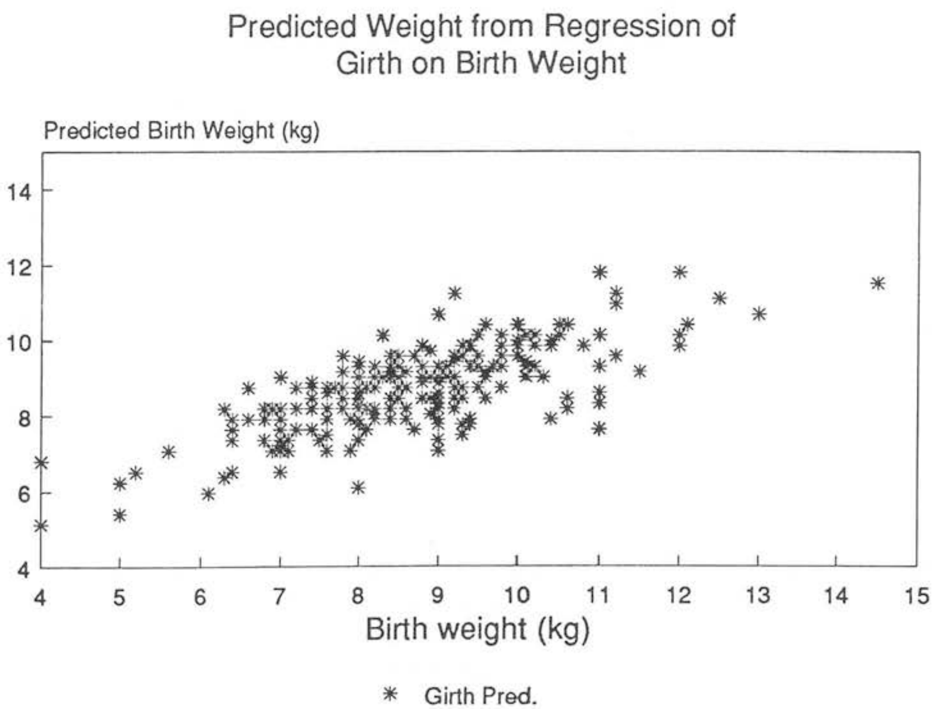
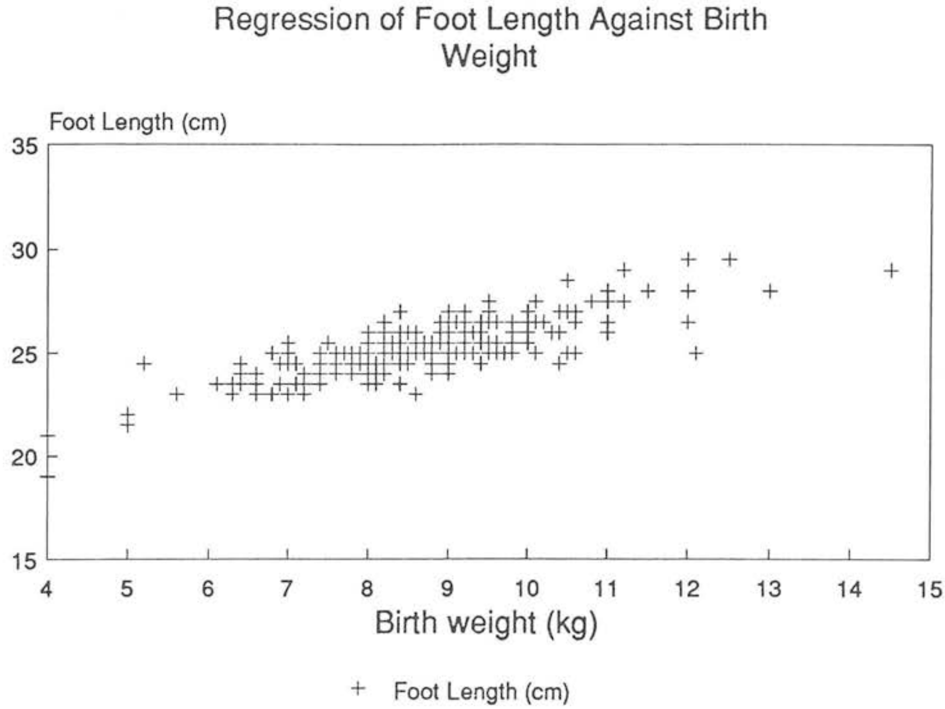


Figure 7.13 Graphs From the Regression Analysis of Foot Length at Birth Against Birth Weight



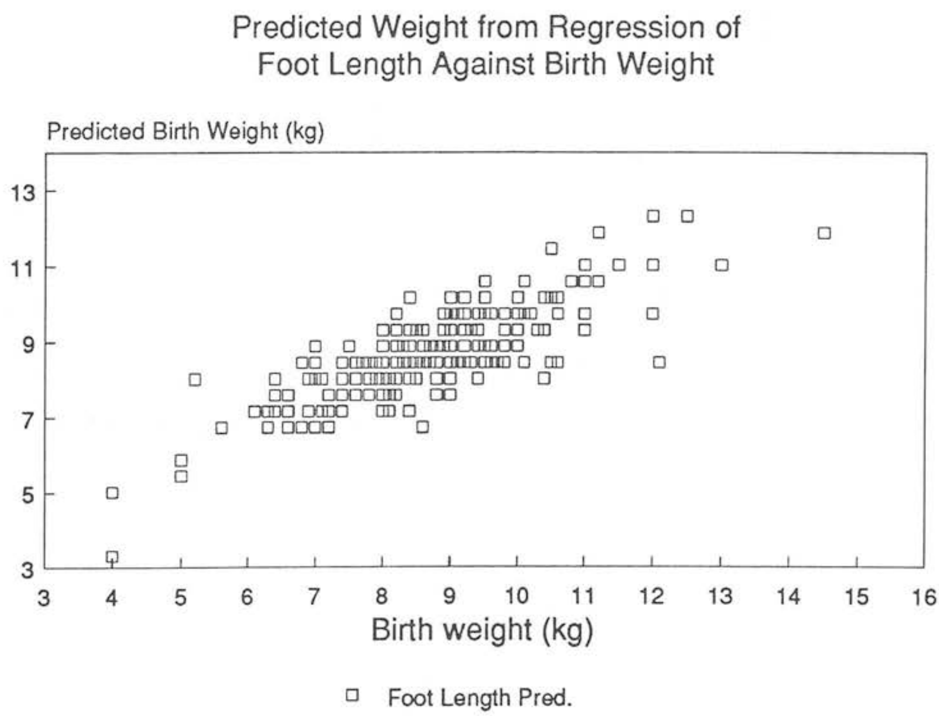


Table 7.16. Simple Regressions for Prediction of Birth Weight of Red Deer Calves.

Trait	Intercept	s.e.	Gradient	s.e.	R^2
All Animals					
Girth	-4.03	0.789	0.278	0.017	53.97
Foot Lth	-12.96	1.072	0.857	0.042	64.70
Male					
Girth	-3.37	1.207	0.267	0.026	47.32
Foot Lth	-13.80	0.890	0.890	0.059	66.00
Female					
Girth	-4.33	1.006	0.279	0.022	60.69
Foot Lth	-12.06	0.819	0.819	0.063	61.38

Multivariate Analysis

Table 7.17 shows results of multiple regression analysis for the prediction of birth weight of Red deer calves using girth and hind foot length. Using both measures substantially improved the ability to predict birth weight by this means. Figure 7.14 shows this graphically.

Table 7.17. Prediction of Birth Weight of Red Deer Calves using Multiple Regression Techniques.

	Intercept	s.e.	Girth	s.e.	FL	s.e.	R^2
All	-13.543	0.904	0.151	0.016	0.606	0.044	0.749
Males	-14.815	1.315	0.137	0.021	0.682	0.060	0.745
Females	-11.978	1.290	0.169	0.023	0.507	0.067	0.743

The correlations of body measures measured at birth with birth weight are shown in Table 7.18. Correlations are for all animals and for males and females separately. Foot length has the highest correlation with birth weight in all cases.

Figure 7.14 Predicted Birth Weight Using Multivariate Model

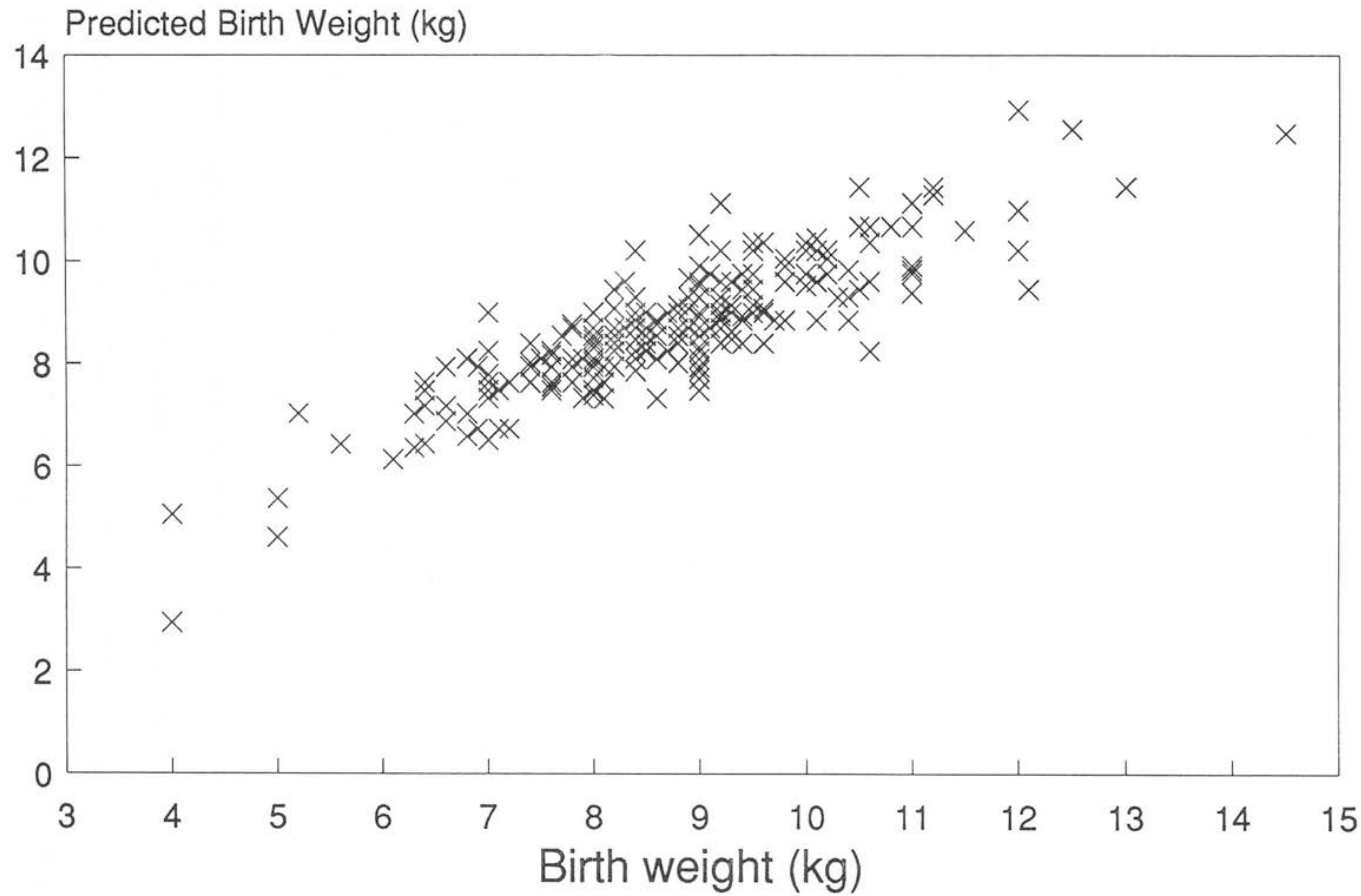


Table 7.18. Correlations of Body Measures at Birth with Birth Weight for a) All Animals b) Males Only and c) Females Only.

a) All Animals

	GIRTH	FOOT LENGTH
WT	0.735	0.804
GIRTH		0.590

b) Males Only

	GIRTH	FOOT LENGTH
WT	0.688	0.812
GIRTH		0.537

c) Females Only

	GIRTH	FOOT LENGTH
WT	0.779	0.784
GIRTH		0.633

7.4 Discussion

This chapter investigates the prediction of certain liveweight and carcass traits by simple and multiplicative regression equations using linear measurements made on the live animal and profile areas taken from photographs. These techniques are well established in the prediction of liveweight. Fisher (1975c) gives a review of the usefulness of live animals measurements as a means of evaluating animals in beef production experiments. He concludes that differentiation between relatively homogeneous groups of animals is possible using this method.

Results from several species show that the heart girth, body length and withers height are useful predictors of weight at various ages in several species (Gruev and Machev, 1970; Patel and Saiyed, 1988; Joshi and Tripathi, 1989; Pander *et al.*, 1989). Results from this study on red deer show the 'best' single regression equation for prediction of liveweight at 15 months was using GF (R^2 = 0.60). Multiple regression techniques (including GF, GB, LSH and WH) improved the accuracy of prediction (R^2 = 0.71).

On the carcass, forequarter, foreleg (total weight and lean weight) and total bone were most accurately predicted (R^2 = 0.65, 0.57 and 0.68 respectively). Fat traits were not well associated with the linear measurements. Deer carcasses have a low proportion of fat in the carcass (0.02 subcutaneous and 0.08 intramuscular) compared with levels of greater than 0.20 found in beef and sheep carcasses (Kempster, 1986). Width of the haunch, length and heart girth were the best predictors for carcass traits. The best predictor of many of the carcass traits was liveweight of the animal at slaughter.

Fisher (1975c) and Taylor (1963) investigated the repeatability and accuracy of linear measurements taken on animals. Fisher (1975) concluded that measurements that estimated skeletal size have the highest repeatabilities, followed by bone + flesh estimates. Estimates of soft tissue alone are the least accurate. This view is supported by results found in his study. Taylor (1963) noted that form 10% to 70% of the total variation within pairs of uniformly treated identical twins could be due to measuring error. Fisher (1975c) commented out that distortion in posture can result in inaccurate measurements. While Touchberry and Lush (1950) conclude that linear body measurements are accurate enough for practical purposes, Fisher (1975c) cautions that this may not be so when applied to a sample of animals which are homogeneous in size and type.

An investigation of the relationship between profile area of beef carcasses and carcass composition was carried out by Fisher (1975b). He found that explanation of variation in muscle weight is poor, but dorsal area and length were almost as good as visual score and side weight in predicting total fat. Prediction of weights of various body parts using the profile area of various body parts in this study had low R^2 values. Including linear measurements in the prediction equations improved the R^2 values for these carcass traits. Orme (1963) noted that relationships among measurements made on live steers and beef carcasses were not high enough for predictive purposes and that the 'eyeball' approach was the best method for predicting carcass shape. The Moire method (Speight *et al.*, 1974; Miles and Speight, 1975) offers an alternative way of recording shape of live animals but would be difficult to apply in the case of deer due to handling difficulties.

In agreement with other studies (Gruev and Machev, 1970; Joshi and Tripathi, 1989), this study showed that birth weight showed a high degree of predictability using heart girth and hind foot length. The prediction of birth weight using multiplicative model incorporating both heart girth and hind foot length had the highest R^2 values (R^2 = 0.743 - 0.759).

The relationships between linear measurements, weight and carcass traits were further investigated by correlation and principal component analyses. This shows how different types of animals can be contrasted and provides a method of objectively grouping traits such that the information in the correlation matrix can be summarised by a linear function of a few traits (Brown *et al.*, 1973; Cameron, 1990).

In the analysis of principal components for traits measured on the live stag the first principal component accounted for 53% of the variation in the 8 measurements. The linear function of size from these traits had nearly equal emphasis on all 8 of the standardised traits. The second principal component contrasted tall, short bodied animals versus those that were broad at the shoulders and had large girths. This contrast in shape accounted for more than 15% of the variation in the dependence structure of the system of 8 variables. With carcass traits, the first two principal components grouped traits into total weights, bone traits and subcutaneous fat traits. Weights related to the hindquarter were closely associated with total weights.

The desired product of the venison industry is an animal which is lean and with a large proportion of the saleable meat in the hindquarter. This study shows that deer have a low proportion of fat in the carcass (0.10 of dressed carcass) and that lean in the hind leg accounted for 0.38 of the total lean in the carcass while the weight of the hind leg accounted for 0.34 of the hot carcass weight. This is in agreement with findings elsewhere (Blaxter *et al.*, 1988). Deer are, therefore, naturally lean animals with large haunches. Lean accounts for 0.75 of the whole carcass.

Fat traits have high coefficients of variation (0.12 - 0.50) and intramuscular fat in particular is moderately to highly correlated with weight traits. Some method of predicting fat proportion in the carcass (such as ultrasonic scanning as used in sheep and cattle breeding) may be desirable to ensure that when selecting animals on the basis of growth-rate or weight for age that there is not a correlated increase in fat in the carcass of the offspring. This method is unlikely to be of use in deer since it measures the thickness of subcutaneous fat on the live animal. Subcutaneous fat accounts for only 0.02 of the deer carcass. Given the temperament of the animals these measurements are also likely to be difficult to carry out on a wide scale. Results here indicate that while prediction of weight of individual body portions is possible the prediction of fat in the carcass has low accuracy using these techniques.

Chapter 8. Evaluation of Relationships Among Immature Measures of Size, Shape and Performance of Stag Calves

8.1 Introduction

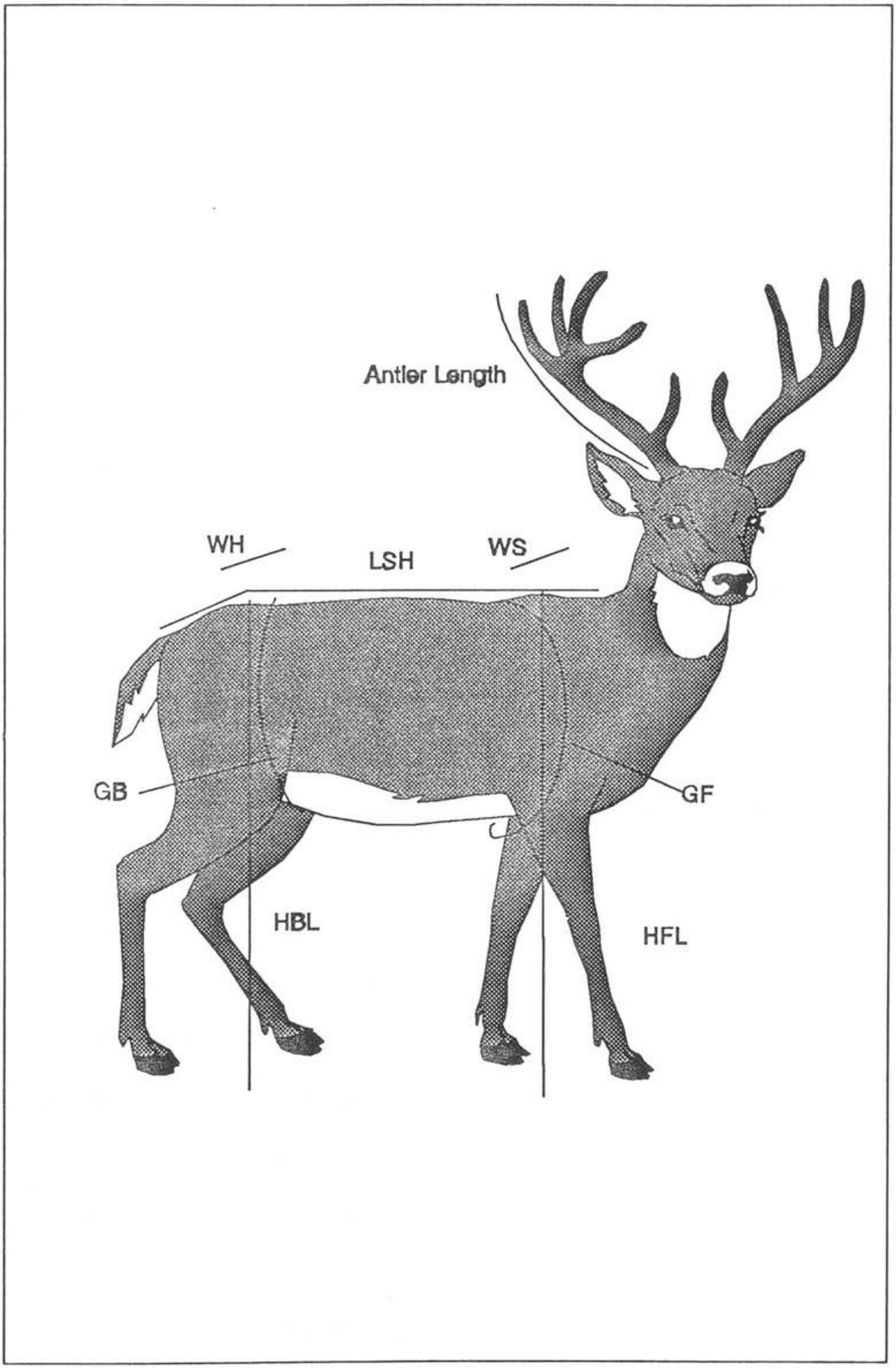
The size of an animal, as an objective measure, is usually measured by weight, but weight does not give information on differences in body proportions of animals. The shape of an animal is usually appraised visually and scored subjectively. A better understanding of the dependence structure among skeletal dimensions at a given age can be achieved by estimating principal components of different body measures. Principal components can also be used to measure differences in size and shape.

The objectives of this chapter were, in addition to investigating the potential of principal components as a means of identifying animals of different shapes, to evaluate the variation in body shape and to measure the tendency of stags to retain the same shapes throughout their preyearling development. The different relationships of linear measurements with weight were also examined.

8.2 Materials and Methods

Data used in this analyses consisted of body weights and measures at 5, 8 and 10 months of age on 83 stag calves which were on central performance test. For rearing details of these animals please refer to Chapter 5. Details of body measurements taken on the animals are given in Chapter 7, which also contains information on the theory behind principal component analyses. A full description of these traits will not be given here but a diagrammatic representation of the linear body measurements are given in Figure 8.1. Chapter 7 also gives details on simple and multiple regression techniques.

Figure 8.1 Measurements taken on Stag Calves on Central Performance Test



HFL = height front leg; HBL = height back leg; GF = heart girth; GB = abdominal girth; LSH = length shoulder to tail head; WS = width of shoulder; WH = width at haunch

8.3 Results

A summary of the body measures taken on animals investigated in this chapter is given in Chapter 5 and will not be repeated here.

8.3.1 Correlations

Correlations between the traits measured in the CPT are given in Table 8.1. Correlations between all the traits tend to be positive and moderate to high in magnitude (except for conditions scores with widths). Weight traits are highly correlated with each other, especially adjacent weights (0.80 - 0.96). Correlations between the other traits are somewhat lower, correlations between heights are the highest and lowest between widths. HFL has the highest correlations with subsequent weights, but most correlations of heights and girths with weight are high, especially those taken on the anterior of the animal (approximately 0.7). Correlations of weight with antler length are generally in the region of 0.5 - 0.6. This relationship is borne out with the covariate analysis presented in Chapter 5.

8.3.2 Prediction of Liveweight

Linear body measurements were used try and predict weight at the various stages of growth (see Chapter 7 for details). Simple regression and multiple regression techniques were used.

Table 8.1. Correlations Between Traits Measured on Animals on Central Performance Test

	WTN	LSHN	HFLN	HBLN	GFN	GBN	WSN	WHN	WTD	WTJ	PEDJ	WTF	PEDF	LSHF	GFF	GBF	HFLF	HBLF	WSF
LSHN	0.63																		
HFLN	0.72	0.65																	
HBLN	0.53	0.61	0.71																
GFN	0.70	0.47	0.54	0.24															
GBN	0.68	0.47	0.54	0.39	0.67														
WSN	0.51	0.46	0.45	0.40	0.47	0.46													
WHN	0.58	0.42	0.51	0.45	0.39	0.47	0.37												
WTD	0.96	0.61	0.73	0.54	0.72	0.67	0.48	0.57											
WTJ	0.88	0.53	0.65	0.50	0.69	0.61	0.42	0.54	0.90										
PEDJ	0.59	0.40	0.45	0.37	0.34	0.42	0.23	0.19	0.55	0.52									
WTF	0.87	0.50	0.64	0.49	0.69	0.65	0.40	0.55	0.92	0.95	0.56								
PEDF	0.56	0.40	0.44	0.38	0.36	0.48	0.25	0.20	0.53	0.51	0.94	0.57							
LSHF	0.58	0.35	0.36	0.32	0.40	0.41	0.24	0.30	0.62	0.59	0.39	0.60	0.36						
GFF	0.75	0.46	0.64	0.40	0.59	0.51	0.44	0.45	0.76	0.77	0.35	0.80	0.36	0.43					
GBF	0.53	0.34	0.43	0.30	0.40	0.34	0.32	0.40	0.56	0.57	0.21	0.62	0.26	0.41	0.72				
HFLF	0.66	0.45	0.61	0.53	0.53	0.42	0.40	0.37	0.68	0.70	0.43	0.70	0.44	0.50	0.62	0.50			
HBLF	0.71	0.47	0.71	0.60	0.61	0.53	0.38	0.49	0.75	0.76	0.44	0.79	0.45	0.60	0.65	0.45	0.79		
WSF	0.31	0.11	0.26	0.17	0.21	0.22	0.20	0.27	0.25	0.32	0.36	0.35	0.39	-0.02	0.32	0.23	0.24	0.21	
WHF	0.38	0.16	0.38	0.27	0.28	0.27	0.11	0.44	0.37	0.37	0.25	0.43	0.30	0.05	0.32	0.38	0.31	0.28	0.51
CSF	0.52	0.33	0.36	0.34	0.32	0.32	0.18	0.33	0.50	0.51	0.39	0.55	0.41	0.12	0.45	0.35	0.35	0.27	0.30
WTA	0.80	0.43	0.62	0.47	0.63	0.54	0.28	0.47	0.84	0.89	0.54	0.92	0.54	0.51	0.78	0.62	0.65	0.66	0.34
PEDA	0.55	0.40	0.46	0.38	0.34	0.37	0.23	0.30	0.47	0.50	0.72	0.55	0.67	0.30	0.45	0.29	0.36	0.44	0.36
HFLA	0.68	0.44	0.66	0.48	0.63	0.51	0.36	0.43	0.71	0.73	0.48	0.75	0.47	0.53	0.61	0.41	0.65	0.72	0.30
HBLA	0.71	0.46	0.71	0.60	0.61	0.53	0.38	0.49	0.75	0.76	0.44	0.79	0.45	0.55	0.65	0.46	0.70	0.77	0.28
GFA	0.70	0.40	0.54	0.47	0.48	0.49	0.27	0.44	0.72	0.77	0.42	0.82	0.44	0.44	0.74	0.55	0.53	0.59	0.29
GBA	0.55	0.30	0.41	0.36	0.38	0.37	0.19	0.40	0.55	0.57	0.37	0.64	0.37	0.31	0.54	0.43	0.38	0.44	0.36
WSA	0.47	0.40	0.43	0.39	0.32	0.28	0.11	0.25	0.44	0.55	0.41	0.52	0.38	0.24	0.46	0.26	0.41	0.37	0.24
WHA	0.55	0.34	0.44	0.44	0.42	0.36	0.31	0.39	0.54	0.55	0.36	0.55	0.39	0.36	0.52	0.47	0.49	0.42	0.29
LSHA	0.66	0.42	0.41	0.34	0.44	0.45	0.22	0.43	0.68	0.73	0.40	0.74	0.39	0.58	0.52	0.41	0.58	0.62	0.18
CSA	0.23	0.06	0.14	0.21	0.12	0.14	0.05	-0.05	0.23	0.28	0.25	0.28	0.27	0.14	0.20	0.28	0.16	0.23	-0.02

	WHF	CSF	WTA	PEDA	HFLA	HBLA	GFA	GBA	WSA	WHA	LSHA
CSF	0.29										
WTA	0.48	0.54									
PEDA	0.34	0.43	0.58								
HFLA	0.36	0.31	0.69	0.52							
HBLA	0.39	0.40	0.76	0.52	0.85						
GFA	0.44	0.44	0.83	0.46	0.56	0.65					
GBA	0.44	0.36	0.66	0.41	0.50	0.54	0.78				
WSA	0.29	0.29	0.55	0.42	0.47	0.42	0.57	0.39			
WHA	0.35	0.32	0.50	0.31	0.59	0.51	0.45	0.33	0.40		
LSHA	0.33	0.43	0.70	0.35	0.57	0.56	0.66	0.48	0.39	0.29	
CSA	-0.02	0.22	0.41	0.24	0.21	0.24	0.25	0.22	0.16	0.21	0.14

Simple Linear Regressions

Table 8.2 gives the results of the linear regression analyses for each of the traits at each of the linear body measurements at each stage of growth. In general heights and girths tended to have the highest predictive ability while widths tended to have the lowest. Girth at the front (GF) was the most useful traits for predicting weight at a certain age (R^2 ranges from 0.48 in November to 0.69 in April).

Table 8.2. Equations for the Prediction of Liveweight From Linear Body Measurements of Stags at 3 Stages on CPT

November Weight

	Const.	Grad.	s.e.grad	R^2
LSH	-23.20	1.05	0.14	0.41
HFL	-51.90	1.26	0.13	0.52
HBL	-20.36	0.88	0.15	0.27
GF	-22.33	0.83	0.09	0.48
GB	-16.00	0.72	0.09	0.46
WS	30.18	2.70	0.49	0.36
WH	18.37	2.71	0.43	0.32

February Weight

	Const.	Grad.	s.e. grad	R^2
LSH	0.70	0.85	0.13	0.45
HFL	-80.10	1.60	0.18	0.49
HBL	-73.90	1.52	0.17	0.49
GF	-65.60	1.32	0.11	0.64
GB	-10.50	0.78	0.11	0.37
WS	51.05	1.94	0.57	0.11
WH	34.24	2.28	0.52	0.18

April Weight

	Const.	Grad.	s.e. grad	R^2
LSH	-25.70	1.27	0.14	0.48
HFL	-73.60	1.61	0.19	0.48
HBL	-113.50	1.97	0.19	0.58
GF	-93.00	1.66	0.12	0.69
GB	-28.90	1.07	0.14	0.43
WS	27.70	4.34	0.74	0.29
WH	31.10	2.82	0.55	0.24

Multiple Regressions

Results for multiple regression analyses are given in Table 8.3. These multiple regression equations show high R^2 values at all stages although the size of the value increases with time (from 0.71 in November to 0.79 in April) and the number of traits in the equation decreases (from 5 to 3).

Table 8.3. Results of Multiple Regression Analysis

November Weight

	coeff.	s.e.	R^2
Const.	-69.22	9.53	0.71
LSH	0.29	0.13	
WH	0.80	0.34	
HFL	0.46	0.15	
GF	0.34	0.10	
GB	0.19	0.09	

February Weight

	coeff.	s.e.	R^2
Const.	-107.33	11.60	0.78
LSH	0.40	0.09	
GF	0.82	0.11	
WH	1.04	0.29	
HFL	0.45	0.16	

April Weight

	coeff.	s.e.	R^2
Const.	-138.30	13.75	0.79
LSH	0.35	0.13	
HBL	0.89	0.18	
GF	0.96	0.15	

Prediction of Turnout Weight from Earlier Measurements

Measurements made in November were used to predict live-weight in April. The results are given in Table 8.4 and this shows that weight in November is the best predictor of weight in April. Height at the front leg and girth at the front are the two linear body measurements which are the best predictors. The prediction of growth rate on test using these measurements was also attempted but no models were significant, all models fitted accounting for less than 1% of the variation in growth rate from November to April.

Table 8.4. Prediction of Liveweight at Turnout using Linear Body Measurements Taken in November

	Const.	Grad.	s.e. grad	R^2
WTN	24.85	1.05	0.09	63.5
LSHN	15.60	0.91	0.21	17.2
HFLN	-36.40	1.40	0.20	38.0
HBLN	-2.90	0.99	0.21	21.1
GFN	-6.20	0.95	0.13	37.4
GBN	10.20	0.75	0.13	28.3
WSN	66.40	1.91	0.72	6.9
WHN	43.68	2.89	0.60	21.4

8.3.3 Principal Component Analysis

Tables 8.5, 8.6 and 8.7 give the component weights from a principal component analysis for weight and linear body measurements at November, February and April. In common with the principal component analyses in the previous chapter the first principal component (PC1) in all 3 cases can be thought of as a measure of general size, as all weights are of similar order and sign.

Table 8.5. Principal Component Weights Obtained From 5 Month Body Measures of Stag Calves

November (5 Month) Weight

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
WT	0.41	0.13	0.09	-0.16	-0.14	0.17	-0.82	0.25
LSH	0.36	-0.24	-0.31	-0.20	-0.62	-0.52	0.11	-0.10
GF	0.34	0.55	-0.09	-0.24	-0.15	0.34	0.50	0.35
GB	0.36	0.40	0.13	-0.11	0.55	-0.58	0.00	-0.22
HFL	0.39	-0.26	-0.01	-0.25	0.13	0.49	0.08	-0.67
HBL	0.33	-0.61	-0.07	-0.06	0.43	-0.01	0.16	0.55
WS	0.31	0.11	-0.51	0.78	0.07	0.10	-0.05	-0.07
WH	0.31	-0.09	0.78	0.44	-0.25	-0.03	0.18	0.00
%VAR	58.66	11.71	8.11	7.37	4.87	4.12	2.69	2.45

Principal Components at 5 Months

The principal components (PCs) obtained for stag calves at 5 months of age are presented in Table 8.5. The first principal component ($PC1_5$) shows nearly identical coefficients for each of the eight body measures and accounts for almost 59% of the variance structure of these traits. In general, the second principal component ($PC2_5$) describes a shape contrast small, short bodied animals with those of large girths. Those animals with negative values for $PC2_5$ could be described as 'rangy' type animals, while those with positive values are more 'compact'. The first two PCs for 5 month measures accounted for over 70% of the variation in the system of eight variables.

Measures of the same sign vary together - the magnitude of the coefficient being proportional to the degree of covariation (Brown *et al.* 1973). Signs of coefficients for PC2 indicate that animals which are more 'compact' tended also to be heavier than the 'rangy' type, although weight does not have a high coefficient. Interpretations of a PC are unique to that PC and do not exclude the possibility of the existence of other possibilities in another PC. The frequency of relationships described by a PC are proportional to the variation accounted for by that PC.

The additional PCs are useful for 'type' characterisation of animals (Brown *et al.*, 1973). For example $PC3_5$ describes animals which are wide at the hips and narrow at the shoulders and tend to be short bodied. The other components can be interpreted in a similar manner.

Table 8.6. Principal Component Weights Obtained From 8 Month Body Measures of Stag Calves

February (8 month) Weight

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
WT	0.44	-0.02	0.00	-0.02	-0.11	-0.51	-0.44	0.58
LSH	0.31	-0.45	-0.14	0.35	-0.69	0.10	-0.01	-0.29
GF	0.41	0.00	0.36	-0.37	0.10	-0.44	0.15	-0.58
GB	0.36	0.04	0.71	0.07	-0.01	0.53	0.10	0.27
HFL	0.40	-0.13	-0.33	-0.09	0.45	0.42	-0.52	-0.24
HBL	0.40	-0.20	-0.40	-0.06	0.24	0.01	0.71	0.29
WS	0.20	0.64	-0.28	-0.45	-0.47	0.24	0.03	0.00
WH	0.24	0.58	-0.06	0.72	0.17	-0.14	0.08	-0.18
%VAR	54.47	17.04	8.44	6.37	6.01	3.67	2.58	1.41

Principal Components at 8 and 10 Months

Principal components were also obtained using 8 body measures at 8 and 10 months of age. The PC_8 are presented in Table 8.6 and PC_{10} in Table 8.7. Three components were required to account for approximately 80% of the variation in the system of 8 variables at 8 months of age, and 5 to account for over 90%. These figures are also true for components at 5 and 10 months of age.

The first components at 8 and 10 months of age ($PC1_8$ and $PC1_{10}$ respectively) were very similar to $PC1_5$ and was interpreted similarly, as a general size component. The remaining components at 8 and 10 months can be individually interpreted in the manner already discussed.

Table 8.7. Principal Component Weights Obtained From 10 Month Body Measures of Stag Calves

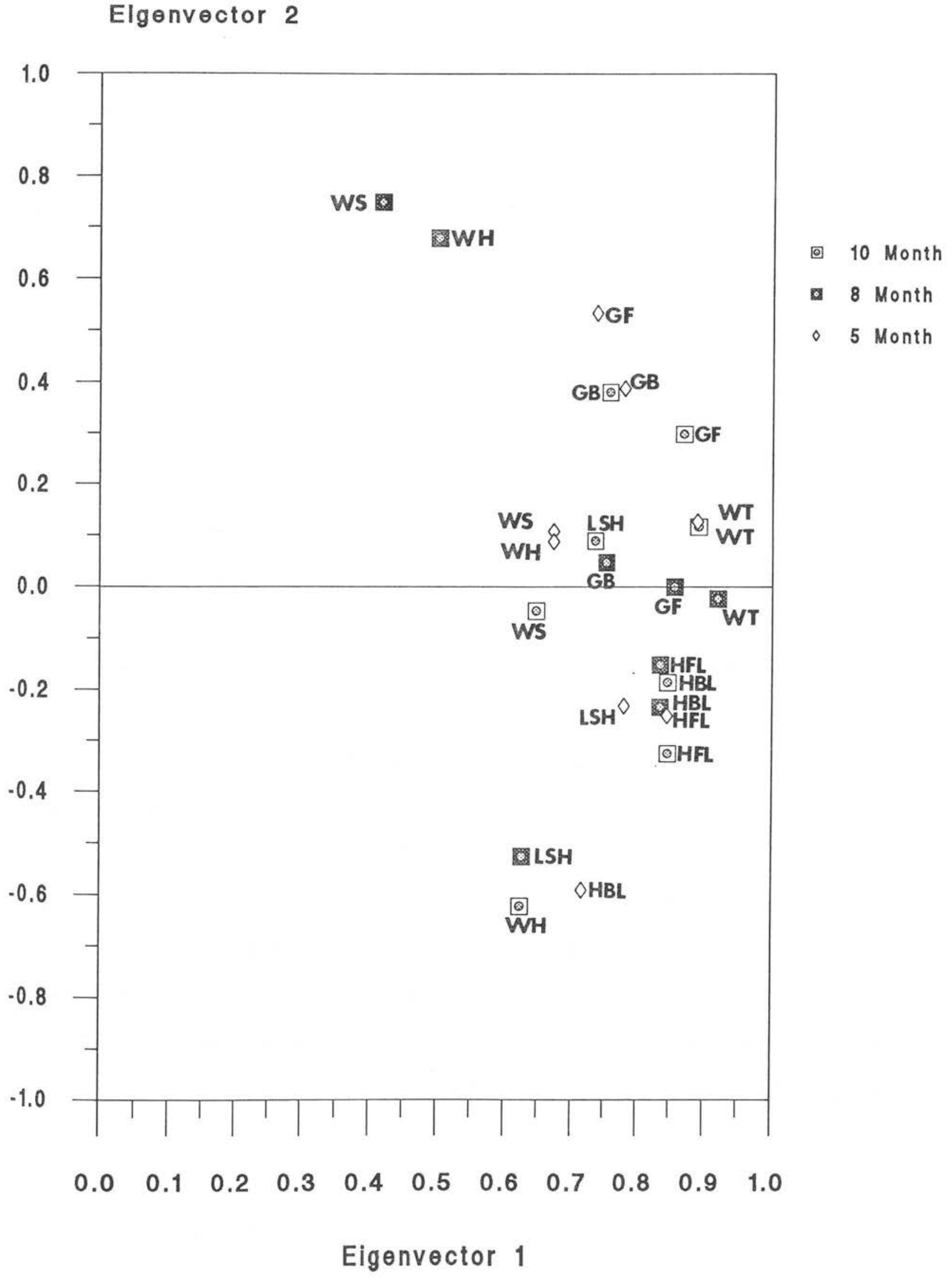
April (10 month) Weight

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
WT	0.40	0.12	-0.06	-0.05	-0.06	0.57	-0.67	0.05
LSH	0.33	0.31	-0.26	-0.55	-0.52	-0.33	0.10	0.18
GF	0.39	0.32	0.16	0.19	-0.14	0.32	0.51	-0.55
GB	0.34	0.41	0.04	0.63	0.14	-0.46	-0.15	0.25
HFL	0.38	-0.35	-0.28	-0.14	0.33	-0.39	-0.20	-0.57
HBL	0.38	-0.20	-0.36	-0.04	0.44	0.26	0.43	0.48
WS	0.29	-0.05	0.82	-0.37	0.26	-0.12	0.00	0.15
WH	0.28	-0.67	0.15	0.33	-0.56	-0.04	0.04	0.13
%VAR	62.31	10.77	8.58	6.99	5.31	3.08	1.65	1.30

There are many similarities between PC3, PC4 and PC5 at various ages, particulary when these 3 vectors are examined together. For example a description of animals with wide hips and shoulders and small stature and short body exists in $PC4_5$, $PC2_8$ and $PC3_{10}$, while $PC3_5$, $PC4_8$ and $PC4_{10}$ describe narrow shouldered, wide haunched animals, and in the case of $PC3_5$ and $PC4_{10}$ this description also includes short animals.

Figure 8.2 gives a graphical representation of the first 2 eigenvectors for the 8 measures at 5, 8 and 10 months of age. The X-axis is dominated by weight, while the Y-axis contrasts heights with girths. Measurements taken on the fore and rear of the animal tend to vary with each other. Weights, heights and

Figure 8.2 Graphical representation of the First Two Eigenvectors for Traits Measured on Live Animal at 5, 8 and 10 Months of Age



girths are also quite repeatable over the 5 month period and therefore provide useful information, while length and widths of shoulder and haunch are highly variable.

8.4 Discussion

Visual appraisals of shape very subjective, and accuracy depend to a large extent on the experience and expertise of the assessor. This chapter attempts to characterise and describe changes in size and shape over time using regression, correlation and principal component techniques.

Variables such as PC1 and PC2 give quantitative definition to qualitative observations on size and shape, often described by descriptive adjectives, such as large, small, blocky, rangy, compact, etc. Components with negative and positive coefficients and those with large and small values within each sign group were contrasted. The magnitude and sign of a coefficient in the PC determines the importance and grouping of a variable. Several authors (Brown *et al.*, 1973, Carpenter *et al.*, 1978; Arthur and Ahunu, 1989) imply that individuals with large values for one measure will tend to have large values for other measurements taken at the same stage of maturity. This is borne out by this study. The principal components found here broadly agree with those found in Chapter 7 for animals weighed at 16 months of age.

Heights and girths tended to have the highest predictive ability for weight at all ages. This is discussed in the previous chapter. The results presented here point, not only to the usefulness of height and girth of the animal to predict liveweight at a certain stage of maturity, but also to contrast animals of different shapes.

Chapter 9. Conclusions and Recommendations for Future Research

The aim of this thesis was to examine genetic and phenotypic aspects of the performance of farmed Red deer. This performance relates to traits involved in reproduction and production. The examination of sources of variation in traits of economic importance is of interest in all farming systems, while the estimation of genetic parameters is necessary for the development of breeding programmes for the genetic improvement of deer.

Deer farming in the UK is a relatively new industry and research to date has concentrated on management and nutrition aspects of deer production. The deer farming industry in the UK is not supported by grants or subsidies akin to those available for conventional farming enterprises, and so operates on a 'free market' system. This is not the only respect in which deer farming differs from other meat farming enterprises. Chapter 2 attempts to highlight areas where deer farming differs from conventional farming enterprises and looks at the areas where research into aspects of breeding can benefit the farmer.

Farmers need to select their replacement stock on a number of economically important traits which can be measured objectively. For this to be carried out effectively the deer industry needs the establishment of accurate and uniform procedures for measuring and recording performance data. These should enable farmers to develop individual programs consistent with their own market. Development of cooperation among all segments of the industry for the compilation and utilisation of performance records to improve the efficiency of production is also necessary and emphasis should be put on the use and interpretation of performance data in improving the efficiency of production. All this is necessary to ensure that breeders and farmers alike have confidence in the potential of performance testing (BIF, 1986).

Chapters 3 and 4 look at the estimation of genetic and phenotypic parameters for Red deer using on-farm records. Problems with the estimation of these arose due to small herds and lack of records due to there being data for few years. The deer industry is relatively young, and many farms have only been established for a few years. As herd numbers are being built up at present (almost all farmers questioned stated an intention to increase their stock numbers) more records for the estimation of parameters are likely to be available in the future.

Selection based on age adjusted weaning weight is likely to improve growth rate and increase weights at all ages. This has implications for increased calving difficulty and mature weight leading to increased maintenance costs. Body weight growth showed an irregular pattern with relatively rapid growth during periods of abundant food and a slower growth during the winter period. Heritabilities of weight traits tended to be higher on farms in better environments. Hind factors were important in pre-weaning traits and remained until turnout. The heritabilities of reproduction traits were low and so a low response to selection would be expected with these traits.

Inbreeding is a potential problem in deer farms due to a low turnover of hinds and stags, with many of the young stock being kept to increase herd numbers, there being little pedigree recording in many cases and little use of records in making breeding (rutting) groups. Many deer farms are stocked from well established deer parks which have had no introduction of 'new blood' for many years. There is a perceived advantage/prestige in keeping lines from these parks 'pure' on farms. This can not only cause inbreeding problems (eg low reproductive rate) but also gives low heritability estimates for growth traits (Chapter 4).

Animals to stock deer farms come from various sources (Scottish hill, English park, Wapiti or East Europe). These animals can be used to produce cross bred progeny at fixed weight or age. Multivariate selection experiments can be used to get precise estimates of parameters for the different 'breeds' as well as investigate heterosis effects using animals from different sources. To estimate the advantages of different crossbreeding systems it is necessary to have a measure of pure-bred performance. Records on pure bred performance for animals which have been imported are very difficult to obtain, as there are very few purebred animals in the country. Mainly stags have been imported.

Crossbreeding makes use of heterosis and the two systems which may be of use in UK deer farms are a two breed terminal cross which uses a purebred hind (eg Scottish or park) and stag of another type (eg Wapiti or European). Using this system you get maximum hybrid vigour in the calf but no maternal heterosis. A three breed terminal cross using an F_1 crossbred hind (Park stag x Scottish hind) and a stag of a third type (eg Wapiti or European) is the other option. This system gives the maximum hybrid vigour in hind and calf.

Selection of the sire is the single most important factor in making genetic progress. If all females are produced within the herd then the sire can be responsible for 100% of the genetic progress. Basic production aspects must be taken into consideration (eg low reproductive rate of the Wapiti) here. Comparisons among individuals between different herds is difficult because of environmental and genetic differences are usually not adequately accounted for (Parnell *et al.*, 1986). The development of multi-herd evaluation procedures is necessary to increase the response to selection. The central performance test (Chapter 5) was established in an attempt to establish across herd links, and to aid farmers in selecting replacement stags. There are many problems with central performance testing including accounting for pretest effects, differences between test and commercial environments and poor representation of individuals from contributing herds. The use of artificial insemination (AI) should be increased to improve the genetic connectedness between herds and so make on-farm records more useful. Many farmers are reluctant to use AI because they wish the deer farming industry to maintain a 'green' image. If AI provided insufficient links then additional links can be made between herds by using reference sires or group breeding schemes. Deer farmers are very reluctant to move animals between farms. This is due to the state of tuberculosis in farmed deer in the country.

There is a lot of discussion in the deer farming industry on the effectiveness of matching hinds and calves at birth or weaning. Several farmers also state that tagging at birth causes mismothering. Genetic fingerprinting could be used to estimate errors in parental identification. It can compare the effectiveness of identification of dam at birth or weaning, and be used to estimate levels of mismothering using both systems.

The formal development of breeding objectives (Chapter 6) highlighted areas in which research can be concentrated in the future. These include carcass traits, evaluation of carcass quality, the need to obtain more reliable estimation of genetic parameters, the estimation of heterotic effects using different 'strains' of animals and aspects of feed consumption/efficiency. For example, if the correlation between growth rate and feed consumption is 1 then no need for it to be included in the objective. Many farmers select on the size of antlers, but these are of no monetary value in this country, except if animals are sold to New Zealand. The market for velvet is decreasing due to increase in farms for the production of velvet in the Orient (Chapter 2).

At the present time the market for farmed venison is not filled and the sale of surplus animals for breeding purposes accounts for a large proportion of the gross margin (Chapter 6). This situation is unlikely to continue indefinitely and those farms which initiate a controlled breeding program now are likely to benefit in the long term.

Many carcass traits cannot be measured directly on the live animal. The use of methods to estimate composition eg ultrasonics needs to be further investigated (Chapter 8). There is a very low level of fat in the carcass of deer but monitoring of this trait is needed, since the sale of venison is dependant on maintaining this low fat percentage in the carcass. In deer this turned out to be difficult, time consuming and dangerous (especially if measured at the rut), but there seem to be few practical alternative methods available. Physiological traits may be useful, eg rate of lipogenesis or rate of protein degradation. Selection of replacement stock, particularly stags, is often also based on conformation and other aspects presumed to be related to carcass composition. Liveweight of the animal accounted for a large proportion of the variation in carcass traits (Chapter 7). Variation in weight can be accounted for, in part, by variation in linear body measurements (Chapter 7, 8). Heights and girths are most closely related to weight and provide a reasonably stable method of estimation.

In many cases, tag numbers of animals were changed at certain times (eg frequently when a hind calf became a hind she was given a new tag). This made it difficult to follow an animal through its life. A tagging system should be unique, reliable and cheap to be effective. The development of a MAFF tagging system, whereby each animal in the country has a unique number which can be related to its herd of origin, should improve the present situation. Some further confusion has arisen because the BDFA introduced a separate tagging system at the same time. It is estimated that up to 10% of all metal ear tags can be lost in any one year (Wilson Committee Report, 1990). Therefore, two ear tags carrying a unique identification number for each animal in the country would be a preferable system. In the future, the introduction of an electronic tagging system would bring many benefits. It could be used in abattoirs, at weighings and when animals are sold, and linked to the herd book register so that information on movement of animals, carcass, herd of origin and links to parents and relatives are relatively easy to collate and disseminate. Carcass information is difficult to obtain at present because many animals are shot in the field and butchered on farm. Abattoir slaughter should provide more information on slaughter traits and improve genetic evaluation for these traits.

The implementation of a centralised recording body for deer would be advantageous. This should have the responsibility for coordinating pedigree recording, weight recording and genetic evaluation. The policy of this could be controlled by the BDFA, BDPS and MAFF. It would provide information for several organisations such as those concerned with animal welfare and human health, as well as summary data for farmers on aspects of management, breeding, and 'breed' and species summaries. All species should be entered in the one data base, so that cross bred animals do not have two different identities. Information on animal movement between farms would also be useful given the high incidence of positive tests for tuberculosis in farmed Red deer. This data base could also be used for future genetic evaluations. Since the deer industry is still relatively small the initiation of such a scheme now will be simpler than if begun when there are more farms and/or animals to be recorded.

This thesis has attempted to highlight the current state of the deer farming industry with respect to breeding and selection of animals. Recommendations to both farmers, on breeding criteria on the basis of present knowledge, and to scientists, on future research objectives, have been made. It is apparent that there is a necessity for a coordinated recording scheme, operated by an independent body, for deer in this country. The type of records which should be kept are outlined in Appendix V. This should be run by an independent body, along the lines of Cattle Data Centre (CDC) as recommended by the Wilson Committee (1990). Since genetic improvement is a slow process, management data should made available to farmers, in conjunction with breeding data to maintain an interest and make better use of the records.

Given the level of recording and the use made of performance records in the deer farming industry in the UK farmers could be advised to save themselves the bother and cost of recording. It is difficult to see the point in taking many records if the records are not used for anything other than to say that 'we record our animals'. Obviously, farmers recognise the importance of recording and genetics in selling breeding stock, but few seem to be willing to do anything positive with their records. Selection of breeding stags, in many cases, is dependent on the number of points of the antler, the spread of the antler or the 'size' of the animal, even on farms which keep detailed performance records on their animals. Advertisements for animals of 'superior genetic quality' abound in the deer farming literature. These are often accompanied by a picture of an adult stag and a caption saying 'This stag had 34 points on his antlers last summer'. So what? Through the derivation of economic breeding objectives, obtaining precise estimates of phenotypic and genetic parameters, setting up across herd genetic linkages and the application of or knowledge of animal breeding animals of genuine superior genetic quality can be identified and optimum genetic progress in the desired direction can be made.

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APPENDIX I. Stratification of the Deer Industry (after Hamilton, 1986)

Wild Red deer

These herds have provided the initial stocks for many deer farms. The best trade is in young hinds and 8 month old hind calves caught in January and February. Some farmers who have bought mature hinds have found that they are broken mouthed and have died soon after introduction to the farm. Mature hinds are also harder to fence train and are difficult to handle.

Hill deer farms

These produce weaned calves which are sold to upland or lowland farms where they grow faster to breeding or slaughter weights. The main features of these farms are the high cost of wintering the calf crop and low growth rate of yearlings. The most attractive proposition is therefore selling weaned calves in October.

Upland deer farms

These breed stags which may be suitable for use on hill farms, and sell breeding stock and store calves to lowland farms. They can also produce venison. Some may export breeding stock and import new blood lines from abroad. The nutritional status and the potential for production are much higher the choice of system includes store-calf production, the production of venison from 16 month old stock, and the production of well grown 16 month old hinds to be sold in-calf during the winter months and breeding stags to be sold in August/September at 27 months of age for the October rut.

Arable lowland deer farms

Arable and lowland farms sell breeding stags to the upland farmer and may import or export livestock as well being the major producer of venison. It is suitable for the production of hybrid cows and bulls, and the farming of crossbred herds for the production of venison at 6-9 months of age. These farms are favourable for all systems but the economics of some systems may be better on upland farms with hill outruns.

Deer parks and zoos

Deer were kept in parks and forests mainly to enhance the parklands surrounding stately mansions and castles and for the production of venison for home consumption. Some parks sell stags, bucks and hinds for breeding purposes. Parks and zoos also hold small herds of exotic species of deer. The most important from a farming point of view are the wapiti, Pere David (both used as terminal cross sires) and sika. Some parks also produce venison.

New Zealand

Currently there is a considerable and lucrative trade in the export of live deer to New Zealand and to the continent of Europe. Some strains of deer species have been imported from Europe to provide an outcross for native strains in the hope of gaining improved vigour, growth rate and possibly antler form. This trade has been hampered in recent years by fears over animal health due to BSE and TB.

Appendix II. INDIVIDUAL FARM DATA

This appendix gives individual summaries for each set of farm data referred to in Chapter 4. Included are parameter estimates for each farm, fixed effect estimates and data summaries as well as a description of the type of farm and stock kept there. No attempt is made to discuss the individual results of each data set as this is summarised in Chapter 4. Table 1 gives a summary of all the data collected from all the farms.

Table 1. Summary of All Data Collected

Farm	DC[1]	BW[2]	WW[3]	MW[4]	TW[5]	OW[6]	Stock[7]
1	√	√				Carcass	Scottish
2	√	√	√		√	1yr/2yr/3yr	English
3	√	√	√		√		English
4			√	√	√		European
5	√		√	√			European+
6	√		√	√	√		English
7	√		√	√	√	1yr	Wapiti
8	√		√	√	√		Inbred English

[1] DC = Date of Calving ; [2] BW = Birth Weight ; [3] WW = Weaning Weight; [4] MW = Mid-winter weight ; [5] TW = Turnout weight ; [6] OW = other weights ; [7] = Origin of breeding stock where Scottish refers to Scottish Hill, English refers to English Park, European refers to European Forests.

Farm 1

Farm 1 is situated in the Scottish Midlands. Stock is mainly from the Scottish hill. This farm recorded date of calving (DC) and weight of calves at birth (BW) and calves and hinds were matched at this stage. No post-birth weights were available, although there was some information on carcass traits (see later).

Birth Traits

Table 1 shows the summary statistics for the two traits measured at birth on Farm 1. Records were available on 551 animals. Birth weight records for Farm 1 were available for 9 years (1982 - 1990). All had the dam identified and were the progeny of 7 sires.

Table 2. Summary Statistics for Birth Weight and Date of Calving on Farm 1.

Trait	No.	μ	σ	cv
Birth Weight	551	8.32	1.18	14.24
Date of Calving	551	11 June	12.19	28.76

Table 3 shows solutions for fixed effects fitted for Farm 1. These included sex of calf, age of dam and year of birth of calf.

Table 3. Least Squares Means and deviations for Fixed Effects on Birth Weight (BW) and Date of Calving (DC) on Farm 1.

	Number	BW (kg)	DC (days)
Sex Male	304	8.45	11 June
Female	243	-0.37 (0.07)	0.59 (0.70)
Dam Age (years) 2	85	7.37	18 June
3	101	0.47 (0.12)	-4.60 (1.21)
4	78	0.67 (0.13)	-7.07 (1.30)
5	73	0.94 (0.13)	-9.35 (1.30)
6	49	1.44 (0.15)	-11.45 (1.51)
7	33	1.30 (0.16)	-12.28 (1.71)
8	30	1.28 (0.17)	-14.05 (1.73)
9	22	1.31 (0.19)	-11.61 (1.95)
10	24	1.23 (0.18)	-10.63 (1.90)
11	20	1.47 (0.19)	-11.85 (2.04)
12	17	1.53 (0.21)	-13.63 (2.17)
13	9	1.36 (0.28)	-14.36 (2.89)
14	6	1.51 (0.33)	-12.12 (3.44)
Year 81	6	8.33	3 May
82	6	1.18 (0.33)	4.67 (2.39)
83	7	0.64 (0.32)	14.86 (2.59)
84	7	1.07 (0.31)	9.05 (2.39)
85	14	0.61 (0.23)	4.05 (3.15)
86	44	0.29 (0.15)	10.40 (2.44)
87	88	0.00 (0.00)	0.00 (0.00)
88	105	0.69 (0.11)	10.94 (3.88)
89	112	0.97 (0.11)	0.97 (0.11)
90	162	0.72 (0.10)	0.72 (0.10)

Carcass Traits

Records were available on 178 animals which were slaughtered between 1986 and 1990. Traits recorded were Gross Dead Weight (GDW), Dead Carcass Weight (DCW) and Kill Out Percentage (KO). The age of the animal in months could also be calculated and so this was fitted as a regression. Table 4. shows a summary of the data.

Table 4. Summary of Carcass Traits for Farm 1.

Trait	μ	σ	cv
GDW	87.46	14.20	16.23
DCW	47.92	8.46	17.65
KO	0.55	0.04	7.55
Age (months)	18.59	5.90	31.72

Table 5. shows correlations and heritabilities for traits measured at slaughter, while Table 6 gives the corresponding solutions for fixed effects for these traits.

Table 5. Heritabilities (on diagonal), Phenotypic (above diagonal) and Genetic (below diagonal) Correlations for Traits Measured at Slaughter on Farm 1 (Figures in brackets are standard errors).

	GDW (kg)	DCW (kg)	KO
GDW	**0.26 (0.19)**	0.89 (0.02)	0.03 (0.08)
DCW	1.00 (0.00)	**0.31 (0.19)**	0.48 (0.06)
KO	1.00 (n.e.)	1.00 (0.00)	**0.59 (0.30)**

Table 6. Least Squares Means and Deviations for Fixed Effects for Traits Measured on the Carcass of Animals Slaughtered on Farm 1 (Figures in brackets are standard errors).

	GDW (kg)	DCW (kg)	KO
Sex Male	88.80	48.45	0.546
Female	-17.99 (5.26)	9.79 (2.78)	-0.018 (0.012)
Year 86	80.19	45.10	0.562
87	9.76 (3.13)	4.84 (1.67)	-0.007 (0.007)
88	5.38 (3.45)	0.33 (1.83)	-0.032 (0.008)
89	2.24 (3.13)	-1.10 (1.66)	-0.028 (0.007)
90	2.66 (2.27)	-1.03 (2.79)	-0.030 (0.012)
Age 1	0.85 (0.27)	0.74 (0.14)	0.003 (0.001)
2	-0.04 (0.01)	0.03 (0.01)	0.000 (0.000)

Farm 2

Farm 2 is situated in East Yorkshire and data was available for 8 years (1983 to 1989). Stock is pure English Park animals. Animals are weighed at birth and matched up to the hind at this stage. They are subsequently weighed at various times throughout the year including weaning and turnout (in April). Some weights of animals at 1 to 3 years of age were also available.

Birth Traits

Birth weights were available on 414 calves and birth dates on 451 animals. Table 7. gives a summary of these traits, while Tables 8 and 9 gives the corresponding least squares means and deviations for fixed effects on these traits and Table 10 shows the genetic and phenotypic correlations between these traits as well as the heritabilities.

Table 7. Summary of Birth Weight and Birth Date at Farm 2.

Trait	Number	μ	σ	cv	min	max
DC (days)	451	11 June	15.55	36.71	18 May	14 Sept
BW (kg)	414	9.29	1.15	15.81	4.1	12.7
WW (kg)	144	51.19	6.24	12.18	28.0	69.0
Age W (days)	144	107.84	16.52	15.32	53.0	144.0
GRBW (kg/day)	144	0.391	0.053	13.45	0.210	0.531

Table 8. Least Squares Means and Deviations for Fixed Effects for Birth Weight (BW) and Date of Calving (DC) on Farm 2 (Figures in brackets are standard errors)

	BW (kg)		DC (days)	
	No. Calves	Means and Deviation	No. Calv.	Means and Deviations
Sex Male	202	9.72	222	11 June
Female	212	-0.77 (0.10)	229	0.29 (1.44)
Hind Age 2	122	8.01	142	16 June
3	83	0.38 (0.15)	94	-6.15 (2.02)
4	59	0.50 (0.17)	65	-7.01 (2.35)
5	53	0.63 (0.18)	53	-5.35 (2.61)
6	47	0.62 (0.19)	47	-10.35 (2.72)
7	27	0.40 (0.23)	27	-7.34 (3.31)
8	16	0.97 (0.28)	16	-11.02 (4.06)
9	7	0.95 (0.47)	7	-11.22 (6.93)
Year 89	92	10.06	96	12 June
88	85	-0.54 (0.18)	85	-3.58 (2.33)
87	63	-0.12 (0.20)	63	-5.91 (2.51)
86	61	-0.36 (0.20)	61	3.23 (2.61)
85	52	-1.42 (0.21)	52	-7.04 (2.72)
84	43	-1.83 (0.22)	47	-2.27 (2.83)
83	14	-2.12 (0.34)		0.52 (2.76)
Date		0.01 (0.00)		

Table 9. Least Squares Means and Deviations for Fixed Effects for Pre-Weaning Traits on Farm 2 (Figures in brackets are standard errors)

	WW (kg)		GRBW (kg/day)
	No. of Calves	Means and Deviations	Means and Deviations
Sex Male	79	52.91	0.413
Female	64	-5.16 (0.03)	-0.050 (0.001)
Hind Age 2	25	49.17	0.370
3	25	2.82 (0.05)	0.010 (0.002)
4	21	3.09 (0.05)	0.011 (0.002)
5	39	3.50 (0.04)	0.017 (0.001)
6	21	3.02 (0.05)	0.002 (0.002)
7	8	5.58 (0.06)	0.024 (0.021)
8	4	6.45 (0.09)	0.011 (0.003)
Year 88	25	50.04	0.409
87	7	4.68 (0.07)	-0.007 (0.002)
86	60	3.54 (0.04)	0.043 (0.001)
85	51	9.56 (0.04)	-0.018 (0.001)
Age		0.36 (0.05)	

Table 10. Heritabilities (on diagonal), Phenotypic (above diagonal) and Genetic (below diagonal) Correlations for Traits Measured on animals on Farm 2 (Figures in Brackets are standard errors).

	BW	WW	GRBW
BW	**0.42 (0.29)**	0.42 (0.03)	0.28 (0.07)
WW	0.49 (n.e.)	**0.22 (0.26)**	0.80 (0.04)
GRBW	1.00 (n.e.)	0.83 (0.08)	**0.29 (0.20)**

A summary of traits measured post-weaning on Farm 2 is given on

Table 11 with Least squares means and deviations given in Table 12 and heritabilities, phenotypic and genetic correlations in Table 13.

Table 11. Summary of Traits Measured on Animals Post-Weaning on Farm 2

Trait	No	X	σ	cv
TW (kg)	50	80.08	13.46	16.40
15 Month (kg)	50	102.86	18.39	17.85
2 Yr (kg)	31	105.97	11.04	11.59
3 Yr (kg)	30	113.57	7.45	6.56

Table 12. Least squares Means and Deviations for Traits Measured Post-weaning on Animals on Farm 2.

	TW	15 Month	2YR	3 YR
Sex Male	100.75	136.38	171.00	
Female	-27.16 (2.16)	-41.55 (3.45)	-66.88 (6.70)	
Year 87	64.42	101.69	102.20	107.17
86	24.12 (2.61)	5.76 (1.36)	4.24 (4.05)	7.00 (3.66)

Table 13. Heritabilities (on diagonal), Phenotypic (above diagonal) and Genetic (below diagonal) Correlations for Traits Measured on animals on Farm 2 (Figures in Brackets are standard errors).

	WW	TW	15Month	2YR	3YR
WW	**0.22 (0.26)**	0.65 (0.03)	0.48 (0.07)	0.72 (0.03)	0.50 (0.01)
TW	1.00 (n.e.)	**0.37 (0.07)**	0.77 (0.12)	0.82 (0.10)	0.93 (0.03)
15 Mth	1.00 (n.e.)	1.00 (n.e.)	**0.71 (0.07)**	0.91 (n.e)	0.50 (0.01)
2YR	0.76 (n.e.)	1.00 (n.e.)	1.00 (n.e.)	**0.42 (n.e.)**	0.75 (0.04)
3YR	1.00 (n.e.)	1.00 (n.e.)	1.00 (n.e.)	1.00 (n.e.)	**0.90 (0.20)**

Farm 3

Farm 3 had data available from 1985 to 1990 calvings. This farm is situated in the north of England and is stocked with primarily English Park animals. A summary of the data is given in Table 14. There were 17 sires used in single mating groups on this farm.

Table 14. Summary of Data from Farm 3.

Trait	No.	X	σ	cv
BW	490	9.38	0.98	10.41
D100	399	41.57	6.80	16.35
TW	287	67.16	9.92	14.77
AgeT	287	313.75	16.41	5.23
DC	704	8 June	11.42	28.75

Tables 15 and 16 give least squares estimates of the means and deviations for the traits measured on this farm. Heritabilities and correlations (genetic and phenotypic are given in Table 17).

Table 15. Least Squares Means and Deviations for Fixed Effects on Birth Weight and Date of Calving on Farm 3 (figures in brackets are standard errors)

	Date of Calving		Birth Weight	
Sex Male	256	6 June	256	9.54
Female	448	1.37 (0.96)	234	-0.36 (0.07)
Hind Age 2	120	19 June	35	8.54
3	156	-6.65 (1.16)	96	0.43 (0.15)
4	164	-8.24 (1.19)	127	0.69 (0.15)
5	145	-11.72 (1.24)	118	0.86 (0.16)
6	87	-14.17 (1.39)	82	0.88 (0.16)
7	32	-14.40 (1.92)	32	1.15 (0.20)
Year 89	292	12 June	291	9.27
90	199	-7.74 (0.85)	199	0.26 (0.08)
88	93	-2.02 (1.11)		
87	40	-8.04 (1.63)		
86	62	-8.62 (1.52)		
85	18	-8.63 (1.86)		
Birth Wt		0.70 (0.36)		

Table 16. Least Squares Means and Deviations for Fixed Effects on Traits Measured After Birth on Farm 3 (Figures in brackets are standard errors)

	100 Day Wt		TW (kg)	
Sex Male	90	44.85	146	73.11
Female	309	-4.00 (0.91)	141	-12.33 (0.85)
Hind Age 2	116	39.09	33	64.98
3	120	2.18 (0.86)	80	1.98 (1.47)
4	81	2.23 (0.95)	74	3.01 (1.52)
5	64	5.31 (1.03)	50	3.98 (1.60)
6	18	3.81 (1.65)	47	3.80 (1.68)
7			3	2.74 (4.31)
Year 89	191	42.98		
88	91	1.99 (0.91)		
87	40	-2.02 (1.17)		
86	60	-1.61 (1.06)		
85	17	-1.00 (1.75)		
Age				0.13 (0.03)

Table 17. Heritabilities (on diagonal), Phenotypic (above diagonal) and Genetic (below diagonal) Correlations for Traits Measured on Farm 3 (Figures in brackets are standard errors)

	BW	D100	TW
BW	**0.31 (0.15)**	0.43 (0.06)	0.36 (0.08)
D100	0.70 (0.22)	**0.67 (0.29)**	0.43 (0.08)
TW	1.00 (n.e.)	0.37 (0.51)	**0.40 (0.27)**

Farm 4

Farm 4 is situated in South West Wales. Data was available on 85 calves which were the progeny of 9 sires. While birth dates and weights were unknown the calves were weighed at weaning, mid winter and turnout. A summary of the data is given in Table 18 with Least squares means and deviations in Table 19.

Table 18. Summary of Data from Farm 4.

Trait	μ	σ	cv
WW	42.98	7.08	16.49
MW	59.59	8.27	13.88
TW	76.31	14.89	19.52

Table 19. Least Squares Means and Deviations for Traits Measured on Animals on Farm 4 (Figures in brackets are standard errors).

	No	WW	MW	TW
Sex Male	18	48.56	66.52	90.37
Female	67	-4.58 (1.35)	-5.69 (1.64)	-11.75 (2.73)
Group[1] 1	28	39.30	55.84	58.20
2	16	-2.89 (1.60)	-0.68 (1.94)	3.77 (4.76)
3	10	5.29 (1.86)	5.32 (2.26)	11.27 (5.04)
4	31	3.87 (1.33)	5.17 (1.61)	15.37 (3.48)
Year 88	29	40.53	54.38	66.75
89	56	4.02 (1.33)	6.86 (1.61)	12.66 (3.28)

[1] Groups are: 1 = Yugoslavian cross; 2= German Cross ; 3 = Pure bred Yugoslavian ; 4 = Pure bred German

Table 20. Heritabilities (on diagonal), Phenotypic (above diagonal) and Genetic (below diagonal) Correlations for Traits Measured on Animals on Farm 4 (figures in Brackets are standard errors).

	WW	MW	TW
WW	**0.69 (0.14)**	0.79 (0.08)	0.40 (0.30)
MW	0.89 (0.12)	**0.42 (0.19)**	0.78 (0.12)
TW	0.29 (0.54)	0.75 (0.29)	**0.42 (0.24)**

Table 20 gives heritabilities, phenotypic and genetic correlations for the traits measured on this farm.

Farm 5

Farm 5 is also situated in the South of Wales. It was established in 1989 and so only two years data is available. This farm is of interest because of the wide diversity of biological types of the deer the farmer keeps on the farm, from Scottish, to English Park to Eastern European Red Deer and hybrids of the above. Animals were not weighed at birth although birth date was noted. The first weighing is at weaning and subsequent dates. Tables 22 and 23 show least squares means and deviations for fixed effects on traits measured on this farm and heritabilities, phenotypic and genetic correlations respectively.

Table 21. Summary of Traits Measured on Farm 5.

Trait	μ	σ	cv
DC	9 June	16.11	39.76
WW	41.68	9.24	22.18
AgeW	100.89	16.29	16.14
MW	59.57	13.92	23.37
AgeM	192.33	45.33	23.57

Table 22. Least squares Means and Deviations for Fixed Effects on Date of Calving (DC), Weaning weight (WW) and Mid-winter Weight (WW) on Animals on Farm 5 (Figures in Brackets are standard errors).

	No.	DC	WW	MW
Sex Male	78	9 June	44.29	62.21
Female	73	-1.43 (2.10)	-2.76 (0.30)	-4.94 (1.33)
Group 1	7	26 May	60.38	73.50
2	7	-4.35 (8.97)	6.29 (1.65)	12.87 (4.29)
3	17	8.85 (7.96)	-0.41 (1.57)	0.81 (3.85)
4	92	15.34 (8.21)	-11.80 (1.45)	-10.85 (9.32)
5	9	21.32 (9.03)	1.09 (1.85)	0.77 (4.62)
6	7	-0.27 (9.72)	1.70 (1.89)	4.82 (5.10)
7	12	6.71 (8.49)	-3.16 (1.67)	-0.41 (4.27)
Hind Age 2	29	54.83	35.43	48.67
3	18	-3.06 (5.02)	-0.64 (0.72)	-8.97 (2.64)
4	27	-8.92 (4.27)	4.13 (0.61)	-4.34 (3.04)
5	42	-8.95 (3.71)	3.22 (0.46)	-2.35 (2.59)
6	35	-13.79 (4.25)	5.92 (0.63)	-3.97 (2.70)
Year 89	40	32.88		66.40
90	111	11.55 (3.63)		-10.30 (3.55)

1 = Pure German; 2 = Pure Hungarian; 3 = Hungarian Cross; 4 = Pure English Park; 5 = German Cross; 6 = Scottish ; 7 = Wapiti Cross

Table 23. Heritabilities (on diagonal), Phenotypic (above diagonal) and Genetic (below diagonal) Correlations for Traits Measured in Farm 5 (standard errors are in brackets).

	WW	MW
WW	**0.89 (0.17)**	0.75 (0.02)
MW	0.72 (0.05)	**0.68 (0.52)**

Farm 6

Farm 6 is located in the midlands of England. Animals are weighed at weaning but birth date is noted. Stock is primarily English Park in origin. Tables 24 and 25 show data summary and least squares means and deviations for fixed effects on Date of Calving for Farm 6 respectively.

Hind Traits

Table 24. Summary Statistics for Date of Calving on Farm 6.

	Number	μ	σ	CV
Date Calving	165	45.07	17.80	39.49

Table 25. Least Squares Means and Deviations for Fixed Effects on Date of Calving (DC) on Farm 6 (Standard errors are in brackets).

	No.	Date of Calving
Sex Male	89	13 June
Female	76	1.41 (1.87)
Hind Age 2	42	23 June
3	14	0.33 (3.56)
4	33	-0.36 (4.58)
5	35	-8.91 (3.72)
6	40	-14.04 (2.70)
Year 87	38	10 June
88	48	14.21 (5.25)
89	79	17.59 (4.47)

Table 26. Summary Statistics for Post-Weaning Traits on Farm 6

	μ	σ	CV
WW	32.21	7.65	23.76
MW	46.84	8.67	18.50
TW	55.40	9.04	16.32
GRBW	0.336	0.077	22.78
GRMT	0.093	0.041	43.93
GRWM	0.356	0.076	22.74
GRWT	0.123	0.038	7.33
WW Age	71.89	16.86	23.45
MW Age	168.69	19.18	30.88
TW Age	263.04	19.29	7.33

Tables 26 and 27 give a summary of the data and least squares means and deviations for fixed effects on postweaning traits on Farm 6 respectively while Table 28 gives the corresponding heritabilities and genetic and phenotypic correlations between these traits.

Table 27. Least Squares Means and Deviations for Fixed Effects on Post-Weaning Traits on Farm 6 (Standard errors are in brackets)

	WW	MW	TW	GRBW	GRWT	GRMT	GRWM	No
Sex Male	34.38	50.27	59.66	0.360	0.137	0.105	0.161	84
Fem.	-4.09 (0.59)	-6.37 (0.74)	-8.64 (0.99)	-0.060 (0.010)	-0.027 (0.001)	-0.025 (0.004)	-0.026 (0.004)	70
Hind Age 2	29.53	46.63	56.22	0.334	0.143	0.112	0.166	38
3	1.44 (1.08)	1.83 (1.80)	1.09 (1.84)	0.034 (0.019)	-0.002 (0.003)	-0.009 (0.008)	0.005 (0.008)	14
4	-1.21 (1.80)	-2.08 (2.98)	1.09 (1.84)	-0.018 (0.031)	0.003 (0.004)	-0.013 (0.011)	0.013 (0.012)	26
5	-0.03 (1.14)	1.45 (1.89)	-2.95 (3.05)	0.015 (0.020)	-0.003 (0.003)	-0.010 (0.008)	0.012 (0.009)	35
6	1.40 (0.88)	-0.79 (1.45)	-0.21 (1.93)	0.023 (0.015)	-0.009 (0.002)	-0.003 (0.006)	-0.013 (0.007)	41
Year 87	33.07	45.69	53.34	0.335	0.101	0.067	0.137	30
88	-3.34 (1.92)	-6.34 (1.74)	-3.44 (2.30)	-0.055 (0.033)	0.000 (0.004)	0.024 (0.012)	-0.029 (0.014)	48
89	-4.34 (1.76)	-1.94 (1.54)	3.88 (2.08)	-0.064 (0.030)	0.055 (0.004)	0.033 (0.011)	0.052 (0.012)	76
W Age	0.35 (0.02)				-0.001 (0.000)		0.000 (0.000)	
T Age			0.20 (0.02)					
M Age		0.23 (0.02)				0.000 (0.000)		

Table 28. Heritabilities (on diagonal), Phenotypic (above diagonal) and Genetic (below diagonal) Correlations for Traits Measured on Animals on Farm 6 (Standard errors are in brackets)

	WW	MW	TW	GRBW	GRWT	GRMT	GRWM
WW	**0.43 (0.29)**	0.59 (0.06)	0.56 (0.05)	0.87 (0.02)	0.15 (0.22)	-0.06 (0.09)	-0.19 (0.09)
MW	0.41 (0.39)	**0.48 (0.29)**	0.82 (0.03)	0.48 (0.06)	0.52 (0.07)	-0.23 (0.09)	0.68 (0.05)
TW	0.90 (0.22)	0.74 (0.17)	**0.45 (0.28)**	0.46 (0.07)	0.73 (0.04)	0.36 (0.08)	0.46 (0.03)
GRBW	1.00 (i.e.)	0.67 (0.34)	-1.00 (i.e.)	**0.39 (0.27)**	-0.54 (0.04)	-0.10 (0.08)	0.18 (0.09)
GRWT	0.87 (0.29)	0.50 (0.26)	0.83 (0.16)	-1.00 (i.e.)	**0.88 (0.31)**	0.45 (0.08)	0.73 (0.05)
GRMT	-0.83 (0.32)	-0.60 (0.32)	0.12 (0.44)	1.00 (i.e.)	0.58 (0.25)	**0.57 (0.28)**	-0.25 (0.09)
GRWM	0.95 (0.11)	-0.37 (0.41)	1.00 (0.00)	-0.43 (0.51)	0.75 (0.15)	-0.24 (0.34)	**0.62 (0.29)**

Farm 7

Farm 7 is situated in the south of England. It is stocked with English and animals with various proportions of wapiti parentage. This farm recorded DC, WW (when the hinds and calves were matched up), TW and weight at 15 months of age.

Table 29. Summary of Data from Farm 7.

	X	σ	CV
DC	6 June	22.41	59.73
Wean	41.57	9.47	22.78
Age W	77.26	17.38	22.50
MW	60.39	10.55	17.46
AgeM	193.45	50.51	26.11
TW	70.24	11.00	15.66
AgeT	322.13	52.15	15.97
AW	93.11	18.73	15.87
AgeA	460.41	54.39	11.81

Table 29 gives a summary of the data from Farm 7 while Tables 30 and 31 gives least squares means and deviations for fixed effects on DC and weight traits respectively.

Table 30. Least Squares Means and Deviations for Fixed Effects on Date of Calving on Farm 7 (Standard errors are in brackets)

	No.	Date of Calving
Sex Male	71	8 June
Female	63	-2.69 (0.04)
Dam Age 2	40	17 June
3	42	-19.65 (0.06)
4	9	-23.83 (0.08)
5	6	-33.94 (0.10)
6	6	-15.92 (0.10)
7	9	-29.16 (0.08)
8	12	-32.67 (0.07)
9	10	-33.73 (0.09)
Prop. of Wap. Parentage 0.061	11	30.73
0.250	7	42.09 (0.11)
0.312	7	-15.90 (0.12)
0.000	109	15.93 (0.08)

Table 31. Least Squares Means and Deviations for Fixed Effects on Post-weaning traits on Farm 7 (standard errors are in brackets).

	No	Wean	MW	TW	Rut
Sex Male	66	44.05	61.97	73.52	107.57
Female	60	-5.05 (1.86)	-6.95 (1.76)	-10.39 (1.82)	-29.79 (2.15)
Wapiti 0.061	11	40.00			
0.250	6	-2.74 (2.05)			
0.312	7	1.16 (3.11)	64.14	71.00	94.71
0.000	102	-8.02 (2.97)	-12.12 (3.01)	-8.89 (3.11)	-6.41 (3.66)
Dam Age 2	33	38.44	54.89	64.68	89.74
3	41	4.38 (3.18)	-0.26 (3.01)	0.45 (3.11)	-3.84 (3.66)
4	9	10.51 (3.44)	6.50 (3.25)	2.87 (3.65)	0.38 (3.96)
5	6	1.12 (2.58)			
6	6	13.10 (2.78)	7.45 (3.46)	10.45 (3.56)	0.00 (4.21)
7	9	13.21 (2.17)	10.67 (2.86)	7.61 (2.95)	8.46 (3.48)
8	12	10.29 (1.97)	14.37 (3.21)	10.85 (3.22)	5.21 (3.91)
9	10	14.52 (3.40)	13.05 (4.33)	9.22 (4.48)	10.53 (5.27)
Age Weigh		0.18 (0.02)	0.17 (0.02)	0.05 (0.02)	0.01 (0.02)

Table 32. Heritabilities (on diagonal), Phenotypic (above diagonal) and Genetic (below diagonal) Correlations for Traits Measured on Animals on Farm 7 (Standard errors are in brackets)

	WW	MW	TW	AW
WW	**0.36 (0.25)**	0.88 (0.07)	0.70 (0.08)	0.33 (0.28)
MW	0.82 (0.29)	**0.33 (0.25)**	0.88 (0.03)	0.71 (0.13)
TW	0.89 (0.19)	0.92 (0.13)	**0.37 (0.25)**	0.88 (0.05)
AW	-0.14 (0.76)	0.70 (0.41)	1.00 (n.e.)	**0.37 (0.25)**

Table 33. Heritabilities (on diagonal), Phenotypic (above diagonal) and Genetic (below diagonal) Correlations for Traits Measured on Animals on Farm 7 (Standard errors are in brackets)

	WW	MW	TW	AW	GRBW	GRWT	GRMT	GRWM
WW	**0.36 (0.25)**	0.88 (0.07)	0.70 (0.08)	0.33 (0.28)	0.71 (0.08)	0.00 (0.02)	-0.28 (i.e)	-0.39 (0.03)
MW	0.82 (0.29)	**0.33 (0.25)**	0.88 (0.03)	0.71 (0.13)	0.57 (0.03)	0.38 (0.01)	0.06 (0.14)	0.37 (0.03)
TW	0.89 (0.19)	0.92 (0.13)	**0.37 (0.25)**	0.88 (0.05)	0.48 (0.10)	0.55 (0.09)	0.48 (0.11)	0.15 (0.13)
AW	-0.14 (0.76)	0.70 (0.41)	1.00 (n.e.)	**0.37 (0.25)**	0.31 (0.10)	0.53 (0.10)	0.17 (0.11)	0.17 (0.12)
GRBW	1.00 (i.e.)	1.00 (0.00)	0.77 (i.e.)	1.00 (i.e.)	**0.57 (1.24)**	-0.09 (0.09)	0.42 (0.11)	-0.54 (0.09)
GRWT	1.00 (0.00)	1.00 (i.e.)	1.00 (i.e.)	1.00 (i.e.)	1.00 (0.00)	**0.17 (0.17)**	0.57 (0.06)	-0.27 (0.12)
GRMT	0.56 (0.72)	-1.00 (0.00)	-1.00 (0.00)	-1.00 (i.e.)	1.00 (0.00)	-1.00 (0.00)	**0.84 (0.69)**	-0.27 (0.12)
GRWM	-1.00 (0.00)	0.70 (0.52)	0.29 (0.94)	1.00 (i.e.)	-0.86 (0.90)	1.00 (0.00)	-1.00 (i.e.)	**0.02 (0.02)**

Farm 8

Farm 8 is located in the South of England. It was established 3 years ago. All the stock for this farm came from a park which has had no new introductions of genetic material for many generations. Since no controlled mating was carried out on the park no information on the pedigrees of these animals is available. On Farm 8 birth of calving but not birth weight is noted. The animals first weighed at weaning. Table 34 gives a summary of the information available from this farm while Tables 35, 36 and 37 gives least squares means and deviations for fixed effects on the traits described in Table 34. Heritabilities, genetic and phenotypic correlations for these traits are given in Table 38.

Table 34. Summary of Statistics for Farm 8

Trait	μ	σ	cv
DC	8 June	12.73	32.96
WW	44.76	6.05	13.53
MW	59.18	6.92	11.70
TW	79.45	11.56	14.55
Age W	98.35	10.93	11.11
Age M	185.82	11.47	6.15
Age T	215.15	10.91	3.46
GRWT	0.159	0.038	24.27
GRMT	0.156	0.055	35.57
GRWM	0.166	0.035	21.40

Table 35. Least Squares Means and Deviations for Fixed Effects on Date of Calving on Farm 8.

	No	Date Calving
Sex Male	63	7 June
Female	69	2.03 (2.31)
Hind Age 2	14	12 June
3	17	-4.32 (4.39)
4	18	-0.17 (5.05)
5	15	-5.62 (4.94)
6	18	-2.51 (5.45)
7	24	-3.21 (6.37)
8	6	-5.22 (7.97)
9	6	-7.72 (6.56)
10	4	-10.26 (5.94)
Year 87	30	10 June
88	44	-0.90 (4.18)
89	58	-3.00 (4.07)

Table 36. Least Squares Means and Deviations for Fixed Effects on Post-Weaning Traits on Farm 8 (Standard errors are in brackets).

	WW	MW	TW
Sex Male	47.07	62.15	86.27
Female	-5.00 (1.56)	-6.67 (1.33)	-16.50 (1.87)
Hind Age 2	41.43	55.43	73.50
3	2.60 (1.66)	3.96 (2.00)	4.70 (3.05)
4	5.49 (2.13)	6.56 (3.06)	8.70 (4.01)
5	2.77 (1.97)	3.40 (2.50)	7.01 (3.62)
6+	4.14 (1.53)	6.18 (2.29)	9.69 (3.54)
Year 87	43.97	59.38	79.14
88	0.66 (1.33)	0.06 (2.12)	0.35 (3.10)
89	2.27 (1.51)		6.56 (6.02)
Age at Weighing	0.20 (0.07)	0.18 (0.06)	0.07 (0.09)

Table 37. Least squares Means and Deviations for Fixed Effects on Growth-Rates on Farm 8 (Standard errors are in brackets)

	GRWM	GRMT	GRWT
Sex Male	0.175	0.190	0.181
Female	-0.021 (0.012)	-0.080 (0.012)	-0.048 (0.009)
Hind Age 2	0.158	0.144	0.148
3	0.011 (0.013)	0.014 (0.013)	0.010 (0.010)
4	-0.003 (0.019)	0.005 (0.019)	0.014 (0.013)
5	0.015 (0.016)	0.042 (0.017)	0.023 (0.012)
6+	0.018 (0.012)	0.021 (0.012)	0.020 (0.009)
Year 87	0.155	0.155	0.161
88	-0.003 (0.010)	-0.012 (0.004)	0.004 (0.008)
89			0.020 (0.009)

Table 38. Heritabilities (on diagonal), Phenotypic (above diagonal) and Genetic (below diagonal) Correlations for Post-Weaning Traits on Farm 8 (Standard errors are in brackets)

	WW	MW	TW	GRWM	GRMT	GRWT
WW	**0.01 (0.03)**	0.84 (0.04)	0.68 (0.00)	0.02 (0.13)	0.06 (n.e.)	0.11 (0.13)
MW	1.00 (n.e.)	**0.01 (0.06)**	0.86 (0.04)	0.55 (0.09)	0.15 (0.13)	0.48 (0.10)
TW	0.98 (n.e.)	1.00 (n.e.)	**0.08 (0.13)**	0.54 (0.10)	0.61 (0.08)	0.80 (0.05)
GRWM	1.00 (n.e.)	1.00 (n.e.)	1.00 (n.e.)	**0.06 (0.14)**	0.19 (0.13)	0.72 (0.06)
GRMT	1.00 (n.e.)	1.00 (n.e.)	1.00 (n.e.)	1.00 (n.e.)	**0.11 (0.22)**	0.79 (0.03)
GRWT	1.00 (n.e.)	1.00 (n.e.)	1.00 (n.e.)	1.00 (n.e.)	1.00 (n.e.)	**0.01 (0.01)**

Appendix III. Central Performance Test

Table 1. Least Squares Means and Deviations for Effects on Linear Body Measurements Taken on Animals over the Period of the Central Performance Test (Standard Errors are in Brackets)

		November		February		April	
LSH	Farm 1	76.93		84.00		90.11	
	2	1.56	(1.98)	0.32	(2.66)	-0.48	(1.90)
	3	-0.33	(0.26)	-0.52	(3.94)	-2.52	(2.97)
	4	1.57	(1.50)	-1.32	(2.03)	-1.46	(1.56)
	5	0.61	(2.82)	1.30	(3.92)	-1.18	(2.94)
	6	1.56	(2.23)	0.19	(2.80)	-4.01	(2.14)
	7	4.46	(2.51)	2.37	(3.22)	-0.31	(2.48)
	8	2.39	(1.71)	0.23	(2.05)	-4.39	(1.57)
	Grp 1	78.07		84.21		88.37	
	2	-0.99	(1.47)	0.24	(1.93)	-0.22	(1.48)
	3	0.76	(2.52)	-1.80	(3.29)	2.69	(2.52)
	4	1.09	(2.23)	2.31	(3.38)	1.20	(2.57)
	5	-2.53	(3.84)	2.00	(5.07)	5.91	(3.86)
	6	-1.21	(3.07)	0.44	(5.41)	-5.16	(4.14)
	Weight	0.42	(0.09)	0.40	(0.09)	0.32	(0.05)
HFL	Farm 1	86.41		94.11		98.00	
	2	1.43	(1.77)	2.31	(1.33)	3.28	(1.53)
	3	1.38	(2.37)	-0.14	(1.97)	5.33	(2.40)
	4	2.68	(1.32)	1.52	(1.01)	2.01	(1.26)
	5	1.97	(2.52)	-1.22	(1.95)	2.09	(2.37)
	6	3.84	(1.99)	1.33	(1.39)	2.21	(1.73)
	7	2.22	(2.24)	4.28	(1.61)	3.26	(2.01)
	8	1.28	(1.53)	-0.57	(1.02)	-0.23	(1.27)
	Grp 1	87.37		95.22		99.14	
	2	-0.58	(1.31)	-1.00	(0.96)	-1.21	(1.20)
	3	-2.64	(2.25)	0.54	(1.65)	-1.12	(2.04)
	4	1.39	(1.99)	1.59	(1.69)	-2.92	(2.07)
	5	-0.79	(3.42)	4.06	(2.52)	-0.13	(3.12)
	6	1.15	(2.74)	-1.24	(2.69)	0.47	(3.34)
	Weight	0.40	(0.08)	0.27	(0.05)	0.26	(0.04)

Table 1 contd

			November		*February*		*April*	
HBL	Farm	1	87.89		95.07		99.85	
		2	3.18	(2.13)	1.16	(1.44)	2.29	(1.18)
		3	-1.63	(2.87)	1.36	(2.12)	2.04	(1.84)
		4	3.29	(1.62)	1.45	(1.09)	1.84	(0.96)
		5	-0.43	(3.06)	-0.91	(2.11)	-1.10	(1.82)
		6	2.79	(2.41)	2.91	(1.51)	1.64	(1.33)
		7	3.04	(2.71)	4.16	(1.74)	3.29	(1.54)
		8	1.32	(1.85)	-0.55	(1.11)	-0.19	(0.97)
	Grp	1	89.47		96.07		100.97	
		2	-0.33	(1.59)	0.08	(1.04)	0.30	(0.93)
		3	-0.27	(2.72)	-0.47	(1.78)	0.55	(1.56)
		4	4.76	(2.41)	0.08	(1.82)	0.33	(1.59)
		5	2.76	(4.14)	4.28	(2.73)	5.01	(2.39)
		6	-0.54	(3.32)	-1.42	(2.91)	0.00	(2.59)
	Weight		0.27	(0.10)	0.32	(0.05)	0.27	(0.03)
GF	Farm	1	95.64		104.04		108.19	
		2	1.39	(2.26)	0.65	(1.53)	0.76	(1.47)
		3	12.93	(3.03)	4.04	(2.27)	-0.44	(2.30)
		4	3.10	(1.72)	1.34	(1.16)	-0.18	(1.20)
		5	7.72	(3.23)	1.78	(2.25)	-1.45	(2.27)
		6	5.62	(2.54)	0.81	(1.61)	-0.19	(1.65)
		7	3.79	(2.87)	1.10	(1.86)	-1.46	(1.92)
		8	5.93	(1.96)	-0.18	(1.18)	-0.30	(1.21)
	Grp	1	97.27		104.77		108.03	
		2	-1.53	(1.68)	1.97	(1.11)	0.28	(1.15)
		3	0.32	(2.88)	-1.80	(1.89)	-1.05	(1.95)
		4	-8.87	(2.55)	-3.16	(1.95)	0.07	(1.99)
		5	-2.13	(4.39)	-8.10	(2.91)	0.76	(2.99)
		6	6.49	(3.51)	-2.53	(3.11)	-2.24	(3.20)
	Weight		0.73	(0.10)	0.45	(0.05)	0.39	(0.04)

Table 1 contd

		November		February		April	
GB	Farm 1	101.14		105.62		108.35	
	2	1.98	(2.81)	-0.52	(2.72)	-0.97	(2.32)
	3	7.36	(3.78)	2.13	(4.03)	-2.43	(3.63)
	4	3.62	(2.13)	2.55	(2.07)	-1.28	(1.89)
	5	6.33	(4.01)	4.85	(4.00)	1.14	(3.59)
	6	6.10	(3.17)	-2.64	(2.86)	0.68	(2.61)
	7	-0.97	(3.57)	0.38	(3.30)	4.83	(3.03)
	8	2.37	(2.43)	0.56	(2.09)	0.06	(1.91)
	Grp 1	101.97		106.36		108.27	
	2	-3.92	(2.09)	2.57	(1.97)	-0.06	(1.81)
	3	-3.56	(3.58)	-1.11	(3.37)	-5.38	(3.07)
	4	-5.45	(3.18)	-1.63	(3.45)	0.28	(3.13)
	5	-6.74	(5.46)	-11.28	(5.18)	-2.52	(4.71)
	6	5.13	(4.37)	1.33	(5.52)	2.24	(5.04)
	Weight	0.69	(0.12)	0.47	(0.09)	0.42	(0.07)
WS	Farm 1	10.00		10.81		13.46	
	2	1.53	(0.66)	1.14	(0.77)	0.82	(0.52)
	3	1.99	(0.89)	0.97	(1.14)	-0.92	(0.81)
	4	1.04	(0.50)	1.34	(0.59)	0.44	(0.42)
	5	0.70	(0.95)	1.70	(1.13)	-0.31	(0.80)
	6	0.76	(0.75)	0.27	(0.81)	0.51	(0.58)
	7	0.01	(0.84)	0.07	(0.93)	-0.24	(0.68)
	8	-0.13	(0.57)	-0.02	(0.59)	0.03	(0.43)
	Grp 1	10.43		11.28		13.68	
	2	0.17	(0.49)	-0.07	(0.56)	-0.16	(0.40)
	3	0.17	(0.84)	-0.26	(0.95)	-0.76	(0.69)
	4	-1.45	(0.74)	-0.94	(0.98)	0.44	(0.70)
	5	-1.29	(1.29)	-0.73	(1.47)	-0.23	(1.05)
	6	-0.63	(1.03)	0.38	(1.56)	0.15	(1.13)
	Weight	0.05	(0.03)	0.04	(0.03)	0.06	(0.01)

Table 1 contd

WH	Farm 1	15.14		16.97		18.88	
	2	0.19	(0.73)	-0.03	(0.77)	1.72	(0.63)
	3	0.63	(0.98)	0.23	(1.15)	1.93	(0.98)
	4	-0.22	(0.56)	0.57	(0.59)	1.70	(0.52)
	5	0.49	(1.04)	1.57	(1.14)	-0.79	(0.97)
	6	-1.07	(0.82)	0.56	(0.81)	-1.13	(0.71)
	7	-0.20	(0.93)	-0.98	(0.94)	0.83	(0.82)
	8	-0.98	(0.63)	-0.70	(0.60)	0.06	(0.52)
	Grp 1	14.77		16.90		19.47	
	2	0.33	(0.54)	-0.66	(0.56)	-0.22	(1.48)
	3	0.38	(0.93)	-0.23	(0.96)	2.69	(2.52)
	4	-0.80	(0.83)	-0.11	(0.98)	1.20	(2.52)
	5	-0.89	(1.42)	0.18	(1.47)	5.91	(3.86)
	6	-0.79	(1.14)	-0.16	(1.57)	-5.16	(4.14)
	Weight	0.08	(0.03)	0.07	(0.03)	0.03	(0.05)

Table 2. Least Squares Means and Deviations for Effects on Feet, Pedicle Development, Temperament and Conditions Score of Animals on Central Performance Test (Standard Errors are in Brackets)

			January		February		April	
Feet	Farm	1	3.31		3.04		2.42	
		2	-0.61	(0.38)	-0.19	(0.51)	-0.12	(0.37)
		3	-1.88	(0.57)	-1.76	(0.76)	-0.34	(0.58)
		4	-0.56	(0.29)	-0.13	(0.39)	0.05	(0.30)
		5	-1.31	(0.56)	-0.32	(0.75)	0.15	(0.58)
		6	-1.48	(0.42)	-0.82	(0.54)	-0.86	(0.42)
		7	-1.33	(0.48)	-0.63	(0.62)	-0.66	(0.49)
		8	-0.79	(0.31)	-0.44	(0.39)	-0.02	(0.31)
	Grp	1	2.74		2.78		2.31	
		2	-0.56	(0.28)	-0.73	(0.37)	0.00	(0.29)
		3	-0.25	(0.48)	-0.71	(0.63)	-0.13	(0.49)
		4	0.53	(0.50)	0.44	(0.65)	-0.24	(0.50)
		5	-0.02	(0.75)	-0.71	(0.97)	-0.55	(0.76)
		6	-0.86	(0.80)	0.03	(1.03)	-0.83	(0.81)
	Weight		-0.01	(0.01)	-0.05	(0.02)	0.02	(0.01)
Pedicle	Farm	1	1.27		2.90		9.04	
		2	0.54	(0.58)	0.72	(1.40)	4.41	(2.49)
		3	-1.91	(0.88)	-5.32	(2.08)	1.30	(3.90)
		4	0.11	(0.46)	0.28	(1.06)	3.90	(2.04)
		5	-0.62	(0.86)	-3.09	(2.06)	1.96	(3.86)
		6	0.08	(0.63)	0.41	(1.47)	5.91	(2.81)
		7	-0.67	(0.73)	-1.59	(1.70)	-2.39	(3.26)
		8	-0.17	(0.48)	-0.22	(1.08)	1.58	(2.06)
	Grp	1	1.21		3.06		11.03	
		2	-0.18	(0.43)	-0.52	(1.02)	-0.24	(1.94)
		3	-0.86	(0.74)	-2.29	(1.73)	-8.48	(3.30)
		4	0.68	(0.76)	2.79	(1.78)	-5.11	(3.37)
		5	0.21	(1.14)	2.16	(2.67)	-2.47	(5.06)
		6	-0.13	(1.22)	-0.29	(2.84)	-3.58	(5.43)
	Weight		0.08	(0.02)	0.22	(0.05)	0.37	(0.07)

Table 2.contd

		January		*February*		*April*	
Temp	Farm 1	2.15		2.88		2.77	
	2	0.02	(0.40)	-0.17	(0.40)	-0.42	(0.33)
	3	0.15	(0.60)	0.67	(0.60)	1.30	(0.52)
	4	-0.71	(0.31)	-0.83	(0.31)	-0.52	(0.27)
	5	-0.79	(0.59)	-0.20	(0.59)	-0.06	(0.52)
	6	-0.16	(0.43)	-0.47	(0.42)	-0.70	(0.38)
	7	-0.28	(0.50)	-0.27	(0.49)	-0.20	(0.44)
	8	-0.13	(0.33)	-0.43	(0.31)	0.08	(0.28)
	Grp 1	1.98		2.51		2.57	
	2	0.39	(0.30)	0.03	(0.29)	0.12	(0.26)
	3	0.09	(0.51)	0.56	(0.50)	0.43	(0.44)
	4	0.69	(0.52)	0.44	(0.51)	-0.22	(0.45)
	5	0.08	(0.78)	-0.54	(0.77)	0.08	(0.68)
	6	-1.04	(0.84)	-0.43	(0.81)	-0.22	(0.73)
	Weight	-0.04	(0.02)	-0.03	(0.02)	-0.02	(0.01)
CS	Farm 1	2.77		2.65		2.57	
	2	0.15	(0.26)	-0.05	(0.15)	-0.24	(0.13)
	3	0.61	(0.40)	-0.50	(0.22)	-0.29	(0.21)
	4	-0.14	(0.21)	0.02	(0.12)	-0.02	(0.11)
	5	-0.17	(0.40)	-0.01	(0.22)	-0.53	(0.21)
	6	0.25	(0.29)	-0.38	(0.16)	-0.10	(0.15)
	7	0.74	(0.35)	-0.12	(0.18)	0.16	(0.17)
	8	0.37	(0.22)	-0.14	(0.12)	0.10	(0.11)
	Grp 1	2.96		2.60		2.58	
	2	-0.35	(0.20)	0.12	(0.11)	0.13	(0.10)
	3	0.03	(0.34)	0.15	(0.19)	-0.01	(0.18)
	4	-0.36	(0.35)	0.32	(0.19)	0.14	(0.18)
	5	-0.17	(0.52)	-0.17	(0.28)	0.18	(0.27)
	6	0.62	(0.56)	0.08	(0.31)	0.24	(0.29)
	Weight	-0.05	(0.01)	0.02	(0.01)	0.02	(0.00)

Appendix IV Absolute Economic Values for Traits in the Breeding Objective

Table 1. Economic Values for Traits in Breeding Objective using Profit Equation and Discounted Gene Flow

Trait	Income and Expense	Discounted Gene Flow					
		0.00	0.02	0.05	0.10	0.15	0.20
Opt.	1	2	3	4	5	6	7
NCW	203300	161684	127002	97035	62270	42266	30068
hFC	-19.20	-15.27	-12.34	-9.16	-5.88	-3.99	-2.84
oFC	-33.15	-27.50	-24.00	-20.00	-15.04	-12.47	-10.38
hCW	287.28	246.70	194.71	139.54	85.27	55.40	37.85
sCW	1251.63	1037.52	906.18	755.39	583.70	470.91	391.98
fLW	1166.22	966.83	844.36	703.91	543.82	438.90	365.25

Table 2 Economic Values Calculated by Altering Fixed Costs and Derived Using Φ

Trait	Levels of Fixed Costs (x 10^{-4})					
	0.00	0.10	0.30	0.50	0.75	1.00
Option	8	9	10	11	12	13
NCW	17556.36	16913.87	15423.08	13994.98	12450.25	11169.1
hFC	-5.14	-4.10	-2.77	-1.99	-1.42	-1.05
oFC	-8.87	-7.07	-4.79	-3.45	-2.44	-1.82
hCW	32.64	29.51	24.75	21.29	18.13	15.78
sCW	142.20	128.60	107.80	92.79	78.99	68.96
fLW	135.00	119.80	100.50	86.46	73.61	64.07

Table 3. Economic Values Calculated by Altering Fixed Costs and Derived Using Q

Trait	Levels of Fixed Costs (x 10^{-4})					
	0.00	0.10	0.30	0.50	0.75	1.00
Option	8	9	10	11	12	13
NCW	-3597.9	-4355.0	-5869.3	-7383.5	-9276.3	-11169.1
hFC	1.05	1.05	1.05	1.05	1.05	1.05
oFC	1.82	1.82	1.82	1.82	1.82	1.82
hCW	-6.69	-7.60	-9.42	-11.24	-13.51	-15.78
sCW	-29.15	-33.11	-41.03	-48.96	-58.86	-68.76
fLW	-27.16	-30.85	-38.23	-45.62	-54.84	-64.07

Table 4 Economic Values Calculated by Altering Income and Variable Costs and Derived Using P

Trait	1	2	3	4	5
Option	11	14	15	16	17
NCW	203300	106185	78685	203300	203300
hFC	-19.20	-19.20	-19.20	-18.20	-19.57
oFC	-33.15	-33.15	-33.15	-31.11	-35.53
hCW	287.28	287.28	287.28	287.28	287.28
sCW	1251.63	1251.63	1068.75	1251.63	1251.63
fLW	1166.22	821.66	662.63	1166.22	1166.22

Table 5 Economic Values Calculated by Altering Income and Variable Costs and Derived using Φ (x 10^{-4})

Trait	1	2	3	4	5
Option	11	14	15	16	17
NCW	13994.98	7412.69	4488.03	14336.76	13642.51
hFC	-1.99	-1.37	-1.14	-1.97	-1.96
oFC	-3.45	-2.39	-1.97	-3.37	-3.56
hCW	21.29	-21.79	-25.10	21.69	20.92
sCW	92.79	-94.94	-106.00	94.48	91.16
fLW	86.46	62.33	50.68	89.89	83.22

Table 6 Economic Values Calculated by Altering Income and Variable Costs and Derived Using Q (x 10^{-4})

Trait	1	2	3	4	5
Option	11	14	15	16	17
NCW	-7383.50	-8295.39	-7265.40	-7274.86	-7477.87
hFC	1.06	1.54	1.84	1.00	1.08
oFC	1.82	2.65	3.19	1.71	1.95
hCW	-11.24	-22.61	-36.60	-11.00	-11.47
sCW	-48.96	-77.21	-125.00	-47.94	-49.97
fLW	-45.62	-69.74	-82.04	-45.62	-45.62

Appendix V Proposed Recording System for Deer

Records on hinds:

1) Breeding Date (or date of introduction and removal of stag and date if a second stag is introduced)
2) Pre-rut weight
3) Pregnancy status
4) Calving date
5) Calving difficulty/ ease
   1 No difficulty/ no assistance
   2 Minor difficulty/ some assistance
   3 Major difficulty/ usually mechanical assistance
   4 Caesarian section or other surgery
6) Birth weight of calf
7) Calf history
   1 Alive at weaning
   2 Sold before weaning
   3 Alive at 72 hours but dead at weaning
   4 Alive at birth but dead at 72 hours
   5 Dead at birth
8) Hind reproduction
   1 Hind open, sold
   2 Hind open, rebred
   3 Hind open, died
   4 Pregnancy unknown, sold
   5 Pregnancy unknown, rebred
   6 Pregnancy unknown, died
   7 Pregnant, sold before calving
   8 Pregnant, died before calving
   9 Pregnant, aborted
   10 Hind calved
9) Gestation length
10) Age at first calving
11) Calving interval
12) Prolifacy
   1 One calf
   2 Two calves

Records on Calves

1) ID
2) Sire
3) Dam
4) Sex
5) Birth Date and Birth Weight
6) Weaning Date and Weight
8) Management to weaning
   1 Hind only
   2 Hind and creep feed
   3 Other (eg bottle reared)
7) Turnout weight and date
8) Weight at date at selection for breeding/slaughter
9) Management group and description of management during winter and summer periods, including feeding (type and amount)
10) Antler length, circumference, number of points and dried antler weight once cut off

Records on animals for slaughter

Live animal
1) Liveweight at slaughter
2) Frame/muscling/conformation score
3) Ultrasonic score
5) Average daily gain post weaning

Carcass
1) Hot carcass weight
2) Cold carcass weight
3) Rib-eye area
4) Fat thickness at 12th rib, perpendicular to outside of fat at 3/4 of the length of rib-eye muscle)

Herd Summaries should be produced which include

1) Number of hinds exposed
2) Calving percentage
3) Weaning percentage
4) Hind Summaries
5) Stag (or rut group) Summaries

Each animal should have a unique ear tag identification which can link it to its herd of origin and parents (if known).

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